

STRANGE PLANET



A SOURCEBOOK OF UNUSUAL
GEOLOGICAL FACTS

WILLIAM R. CORLISS
COMPILER

STRANGE PLANET

A SOURCEBOOK OF UNUSUAL
GEOLOGICAL FACTS

Compiled by
WILLIAM R. CORLISS

VOLUME E-1

Published and Distributed by

Copyright 1975 by William R. Corliss

Library of Congress Catalog Number: 74-26-226

ISBN 0-9600712-3-7

First Printing: January 1975

PREFACE

As readers of the sourcebooks STRANGE PHENOMENA and STRANGE ARTIFACTS are well aware, the object of the Sourcebook Project is the collection and organization of data that do not seem to fit within the framework of dominant scientific dogmas. Such anomalous data are often pregnant with meaning for budding scientific revolutionaries. However, it must be admitted that some of the facts swept up are merely curious, posing no obvious threat to the status quo. As the first word in all sourcebook titles has it, there are strange. The present sourcebook on geology probably has more strange, nonrevolutionary data in it than STRANGE PHENOMENA and STRANGE ARTIFACTS, but it is wise not to try to predict the future course of knowledge.

Geology is the prisoner of several dogmas that have had widespread influence upon the development of scientific thought:

1. The Dogma of Uniformity (That the earth's surface was sculptured over an extremely long period of time by geological forces currently in operation. Uniformitarianism is opposed by the Dogma of Catastrophism.)
2. The Dogma of Evolution (That life was simple in the beginning and, in accord with the Dogma of Uniformity, developed slowly into the more complex species of today.)
3. The Ice Age Dogma (That within the last 100,000 years vast ice sheets spread across the high latitudes, leaving behind a rich deposit of debris, altered land forms, and sundry other signs.)

The very nature of the Sourcebook Project insists that some of the data collected controvert these bulwarks of earth science. However, this is done in the spirit of science and not in biased support of those rival dogmas sketched out by Hapgood, Patten, Velikovsky, and other modern catastrophists. Dogmas are useful in focussing thought, but the sharper focus generally cuts out some of the total picture. So, the sourcebooks avoid promoting dogmas and, in fact, question everything and present both sides of all controversies.

I have devoted a great deal of thought to the organization of the sourcebooks. The format is flexible. More material may be added within the framework of categories from any source and any period. Seemingly unrelated data are correlated through the indexes and annotations. Whole new categories can be added if necessary.

The literature dealing with curious geological features has only been scratched. Volume E1, the present volume, represents only a small portion of my collection. Volume E2 will appear in due course as well as STRANGE UNIVERSE, a sourcebook in the field of astronomy, which will have interesting implications (pro and con) for the Dogma of Catastrophism.

The data have been filtered only slightly. Doubtless some hoaxes and honest misinterpretations will be found in the pages that follow. This is unavoidable in a project of this scope. Indeed, it is unavoidable in all phases of inquiry, especially those relying heavily upon observational evidence.

The collecting net I flung into the literature was a broad one. It had to be because (1) valid data and good theories are often published outside the mainstream of scientific thought; and (2) people were just as observant a century or two ago as they are today. Quotations in this volume will demonstrate that they viewed the world with great curiosity and if they sometimes misinterpreted things perhaps they also saw the cosmos through less biased eyes.

Some of the material included here will be labelled "pseudoscience", but some of the data so castigated will be legitimate science a decade hence. Continental drift was essentially pseudoscience in 1950; today, it is called "plate tectonics" and must be considered well-established. Who knows which theories will be favored tomorrow?

I should also add that I have deliberately introduced data—perhaps 25% of the whole—from outside the scientific literature. This was not done because of any lack of material but rather to insure the widest possible spectrum of observations.

Being that this is a sourcebook, I hasten to acknowledge the many writers of papers, letters-to-the-editor, and sundry publications that make up the foundation of this book. Where lengthy quotations are taken from publications still protected by copyright, permission has been obtained from the copyright holder.

William R. Corliss

Glen Arm, MD 21057
January 2, 1975

CONTENTS

	<u>Page</u>
ORGANIZATION OF THE SOURCEBOOKS	E1-1
BIOLOGICAL EVIDENCE	E1-3
MYTHS AND LEGENDS	E1-49
MAGNETIC DATA	E1-85
ORBITAL AND ASTRONOMICAL EVIDENCE	E1-95
UNUSUAL ROCKS	E1-111
STRATIGRAPHIC EVIDENCE	E1-157
TOPOGRAPHIC EVIDENCE	E1-205
SUBJECT INDEX	E1-277
AUTHOR INDEX	E1-281
SOURCE INDEX	E1-282

A breakdown of the sections listed above follows. Use the headings at the tops of the pages to locate specific subsections and entries.

<u>Section Code and Title</u>	<u>Subsection Code and Title</u>
EB Biological evidence	*EBC Fossil clocks
	EBE Extinctions and overkill
	EBM Mammoth graveyards
	EBR Animals in rocks
	EBS Sealevel indicators
EL Myths and legends	ELC Climate changes
	ELD The Deluge
	ELG Phantom lands

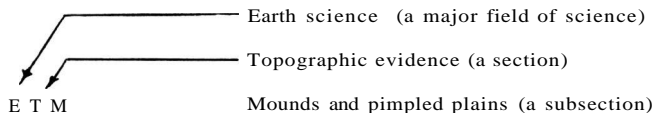
EM	Magnetic data	EMA	Magnetic anomalies
		EMR	Magnetic reversals
EO	Orbital and astronomical evidence	EOA	Astronomical observations
		*EOS	Solar, lunar, and planetary effects
ER	Unusual rocks	ERA	Anomalous rocks
		ERG	Graphic markings
		ERM	Meteorites and tektites
		ERR	Ringing rocks
		ERS	Musical sands
		ERV	Moving rocks
ES	Stratigraphic evidence	ESC	Coal and petroleum
		ESD	The drift
		ESI	"Inverted" strata
		ESP	Patterned ground
ET	Topographic evidence	ETB	Carolina Bays, etc.
		ETC	Craters and astroblemes
		ETE	Emergence and submergence
		ETM	Mounds and pimpled plains
		*ETP	Plans of the earth
		ETS	Submarine canyons

*This subsection not represented in Volume E1.

ORGANIZATION OF THE SOURCEBOOKS

All sourcebook entries are labelled with three letters and a number; viz. , ETM-012. The three letters indicate a category of data. ETM, for example, designates a subsection of the book containing accounts of natural mounds. The number following the letters is simply an acquisition number within that subsection. Thus, entry ETM-012 is the 12th entry in the mound category. The indexes at the back of each sourcebook and all cross references are keyed to the entry label rather than page number. This feature makes it possible to combine like subsections as additional volumes are issued and to provide cumulative indexes.

There is a plan to the assignment of the letter codes. The first letter indicates a broad, general field of science, such as earth science, E. The second and third letters are assigned to sections and subsections within this general field, as illustrated below:



The sections denoted by the second letters are based upon the general features of the earth perceived by an observer, possibly aided by instruments such as magnetometers. All channels of information, such as myth and legend, are included for the sake of completeness.

The subsections (third letters) are narrower in scope than the sections. Experience, however, has shown that subsections must be rather broad to include the wide range of geological evidence in a reasonable number of categories. They cannot be too broad, though, or a structureless hodgepodge results. The subsections have been selected and named with great care to avoid suggesting explanations of the features discussed. A complete list of subsections and sections now in use precedes this page and also functions as a table of contents. Detailed descriptions of the subsections are placed at the beginnings of the sections.

When searching for a specific entry, scan the running heads at the tops of the pages; they give the entry numbers as well as the subsection titles. The person who reads for curiosity's sake will find that each subsection is much like a chapter, with many related items grouped together.

Some larger works, especially books, cover so much ground that their contents have been split up into the appropriate subsections.

The looseleaf format of the sourcebooks is designed to facilitate combining categories as future volumes in the series are issued. Such collation is obviously optional.

ORGANIZATION OF THE SOURCEBOOKS

Each sourcebook is indexed by subject, by author, by source of data, and where useful by time-of-event and place. Each volume is self-contained. With the issuance of additional volumes, cumulative indexes will be compiled. Because all major fields are interrelated, it will doubtless prove valuable to cumulate indexes from volumes on geology, geophysics, astronomy, etc.

References, annotations, and Compiler's Summaries are printed full-width, while the direct quotes that make up the bulk of each sourcebook are indented.

Being a sourcebook, the core of this volume consists of direct quotations from individuals, primarily geologists. The text herein faithfully retains the old spellings, punctuations, and even a few typos. Regurgitations and surveys, so common these days, are already once or twice removed from the observation, and are rarely employed here. The whole object of these sourcebooks is to give the reader and researcher an organized collection of original writings on the unusual facets of nature. Much of this unique information is being lost as libraries become more highly computerized. Data selected for the new data banks must usually have current relevance and be acceptable to the science of the day. Hopefully, these sourcebooks will preserve something of value and help focus the diverse, widely dispersed anomalies on the frontiers of science. At the very least, they should be interesting reading.

SECTION EB: BIOLOGICAL EVIDENCE

Fossils, bones, living animals (rarely), and organic remains in various states of preservation are vital to geologists in reconstructing the timing and nature of past geological events, usually according to the uniformitarian dictum of slow change. The same evidence is employed by the neocatastrophists, the modern representatives of Cuvier and Buckland, to show that geological changes have instead been very rapid or catastrophic. Fundamentalists also rely heavily upon biological evidence in their claims that the Biblical record is supported by geology, and as a corollary that life on the earth is of very recent origin. The controversy between uniformitarians and catastrophists is usually muted these days because the two sides have gone separate ways.

- *EBC Fossil clocks. Bivalve growth rings, tree rings, etc., as indicators of length of month, length of year, and other natural time periods.
- EBE Extinctions and overkill. The extermination of species in the fossil record—possibly due to catastrophism of some kind. The frequent occurrence of immense quantities of fossils, their species distribution, and conditions of deposit.
- EBM Mammoth graveyards. Includes the so-called "ivory islands", and the extraordinarily thick deposits of muck and debris around the Arctic Ocean, with their high contents of organic remains.
- *EBO Oil and coal. Unusual features of these deposits and the question of origin.
- EBR Animals in rocks. Frogs, toads, etc., sometimes still alive, according to the reports, as discovered inside rocks.
- EBS Sealevel indicators. Animal and plant remains as evidence of very high sealevels in the past.

•This subsection not represented in Volume E1.

BIOLOGICAL EVIDENCE

Fossils exist, and this fact does not surprise us or stretch the frontiers of scientific theory. But when immense numbers of animals perish, apparently within geologically short times, we must ask what caused the wholesale slaughters. "Extinctions" we now call them. The extinctions we see in the geological record may have had catastrophic causes with huge populations dying and being preserved where they fell, or the abundant corpses may have been concentrated by wind and water following some less-than-catastrophic event. There may be other explanations we have not yet conceived. (The reader should also peruse the EBM subsection dealing with the "mammoth" problem.)

EBE-001 [FISH GRAVEYARDS]

Price, George M. ; Evolutionary Geology and the New Catastrophism, Pacific Press Publishing Association, Mountain View, 1926.

Price, the fundamentalist-catastrophist of the 1920s, questioned (and quite properly, too) the mechanism by which huge numbers of fish were fossilized. It could not be a uniformitarian process, he claimed, for we see no such process today. To Price, this meant only that terrestrial catastrophes were the real mechanisms.

Darwin, in his famous chapter on "The Imperfection of the Geological Record," has well shown how scanty and imperfect are the modern fossiliferous deposits. The progress of research has only confirmed and accentuated the argument there presented on this point. Thus Nordenskiöld, the veteran arctic explorer, remarks with amazement on the scarcity of recent organic remains in the arctic regions, where such a profusion of animal life exists, and he concludes with the following language:

"It is strange, in any case, that in Spitzbergen it is easier to find the vertebrae of a gigantic lizard of the Trias than the bones of a self-dead seal, walrus, or bird, and the same also holds good of more southerly inhabited lands."

It is also an expressive fact in this connection that, in spite of the great numbers of cats, dogs, and other domestic animals that are constantly being thrown into rivers like the Hudson or the Thames, dredgings about the mouths of these streams have revealed the surprising fact that scarcely a trace of any such animals is there to be found.

Even the fishes themselves stand a very poor chance of being buried intact. As Dana puts it:

"Vertebrate animals, as fishes, reptiles, etc., which fall to pieces when the animal portion is removed, require speedy burial after death, to escape destruction from this source [decomposition and chemical solution from air, rain water, etc.], as well as from animals that would prey upon them."

If a vertebrate fish should die a natural death—which, of itself, must be a rare occurrence—the carcass would soon be devoured whole or bit by bit by other creatures near. Possibly the lower jaw, or the teeth, the spines, etc., in the case of sharks, or a bone or two of the skeleton, might be buried unbroken, but a whole vertebrate fish entombed in a modern deposit is surely a unique occurrence.

But every geologist knows that the remains of fishes are, in countless millions of cases, found in a marvelous state of preservation. They have been entombed in whole shoals, with the beds containing them miles in extent, and scattered over all the globe. Indeed, so accustomed have we grown to this state of affairs in the rocks we hammer up, that if we fail to find such well-preserved remains of vertebrate fishes, land animals, or plants, we feel dis-

appointed, almost hurt; we think that nature has somehow slighted this particular set of beds. But where, in our modern quiet earth, shall we go to find fish-deposits now forming like the copper-slate of the Mansfield district, the Jurassic shales of Solenhofen, the calcareous marls of Oeningen on Lake Constance, the black slates of Glarus, or the shales of Monte Bolca?—to mention some cases from the continent of Europe more than usually famous in the literature for exquisitely preserved fishes, to say nothing of other fossils. Or we might mention the black Onondaga limestones of Ohio and Michigan; the Green River beds, Arizona; or the diatom beds of Lompoc, California, as a few examples from America of strata packed full of splendidly preserved fishes.

Buckland, in speaking of the fossil fish of Monte Bolca, which may be taken as typical of all the others is quite positive that these fish must have "perished suddenly," by some tremendous catastrophe.

"The skeletons of these fish," he says, "lie parallel to the laminae of the strata of the calcareous slate; they are always entire, and so closely packed on one another that many individuals are often contained in a single block. . . . All these fish must have died suddenly on this fatal spot, and have been speedily buried in the calcareous sediment then in course of deposition. From the fact that certain individuals have even preserved traces of color upon their skin, we are certain that they were entombed before decomposition of their soft parts had taken place."

In many places in America as well as in Europe, where these remains of fish are found, the shaly rock is so full of fish oil that it will burn almost like coal, while some scientists have even thought that the peculiar deposits like Albertite "coal" and some cannel coals were formed from the distillation of the fish oil from the supersaturated rocks.

De la Beche was also of the opinion that most of the fossils were buried suddenly and in an abnormal manner. "A very large proportion of them," he says, "must have been entombed uninjured, and many alive, or, if not alive, at least before decomposition ensued." In this, he is speaking not of the fishes alone, but of the fossiliferous deposits in general.

There is found in all parts of the world a series of strata which used to be called the "Old Red Sandstone," now known as the Devonian. In this, almost wherever we find it, the remains of whole shoals of fishes occur in such profusion and preservation that the "period" is often known as the "Age of Fishes." Dr. David Page, after enumerating nearly a dozen genera, says:

"These fishes seem to have thronged the waters of the period, and their remains are often found in masses, as if they had been suddenly entombed in living shoals by the sediment which now contains them."

I beg leave to quote somewhat at length the picturesque language of Hugh Miller regarding these rocks as found in Scotland:

"The river bullhead, when attacked by an enemy, or immediately as it feels the hook in its jaws, erects its two spines at nearly right angles with the plates of the head, as if to render itself as difficult of being swallowed as possible. The attitude is one of danger and alarm; and it is a curious fact, to which I shall afterward have occasion to advert, that in this attitude nine tenths of the Pterichthys of the Lower Old Red Sandstone are to be found. . . . It presents us, too, with a wonderful record of violent death falling at once, not on a few individuals, but on whole tribes.

"At this period of our history, some terrible catastrophe involved in sudden destruction the fish of an area at least a hundred miles from boundary to boundary, perhaps much more. The same platform in Orkney as at Cromarty is strewn thick with remains, which exhibit unequivocally the marks of violent death. The figures are contorted, contracted, curved, the tail in many instan-

ces is bent round to the head; the spines stick out; the fins are spread to the full, as in fish that die in convulsions. . . . The record is one of destruction at once widely spread and total, so far as it extended. . . . By what quiet but potent agency of destruction were the innumerable existences of an area perhaps ten thousand square miles in extent annihilated at once, and yet the medium in which they had lived left undisturbed in its operations?

"Conjecture lacks footing in grappling with the enigma, and expatiates in uncertainty over all the known phenomena of death."

I will not taunt the uniformitarians by asking them to direct us to some modern analogies. But I would have the reader remember that these Devonian and other rocks are world wide in extent.

Surely Howorth is talking good science when he says that his masters, Sedgwick and Murchison, taught him "that no plainer witness is to be found of any physical fact than that nature has at times worked with enormous energy and rapidity," and "that the rocky strata teem with evidence of violent and sudden dislocations on a great scale." (pp. 234-239)

EBE-002 SUPERNOVAE AND THE EXTINCTION OF THE DINOSAURS

Russell, Dale, and Tucker, Wallace; Nature, 229:553-554, February 19, 1971.

Early suggestions that supernovae might have been responsible for biological extinctions relied upon biological damage from radiation—an effect which calculations proved to be too small. The present authors postulate terrestrial catastrophism due to the large quantity of energy absorbed by the atmosphere.

We wish to suggest that a nearby supernova explosion might produce climatic effects so drastic as to cause the extinction of many animals, including the dinosaurs. Earlier discussions of this topic focused on the radiation doses to be expected as a result of the interaction of high-energy cosmic rays and γ -rays with the atmosphere. Reasonable estimates of the parameters involved implied doses which may account for some of the patterns of mass extinction observed in the geological record.

The belief that large fluxes of cosmic rays and γ -rays are produced during the early phases of a supernova outburst has been strengthened by the discovery of pulsars. In addition we might expect supernovae to be powerful emitters of soft X-rays during the first few days, as suggested by the identification of several features in the spectrum of type I supernovae as forbidden lines from highly stripped ions such as exist in the solar corona. This requires that the expanding envelope have a temperature of the order of a million degrees, and suggests the existence of large X-ray fluxes. In general, if the efficiency of production of visible light relative to the production of high frequency radiation is small, of the order of a few per cent or less, then $\sim 10^{47}$ ergs in X-rays will be emitted in about a week as a result of a supernova outburst. It will soon be possible to verify or disprove the existence of large X-ray fluxes from supernova outbursts by satellite observations of supernovae in other galaxies.

Estimates of the probabilities for nearby supernovae show that ~ 1 supernova explosion should occur within a distance of 100 light years every 50 million years. As a result of such an explosion, the atmosphere as a whole would absorb about 10^{47} ergs in X-rays in about a week or less, mostly in the ozone layer and the ionosphere between about 20 and 100 km, depending on the spectrum of the radiation. This is a hundred times the far ultraviolet and X-ray flux received from the Sun during a week.

The climatic effects of an enormous deposition of energy into the upper atmosphere are difficult to assess. London has suggested that heating at the top of an atmosphere produces ascending motions in the stratosphere which make the lower atmosphere unstable or aid in the vertical exchange of momentum. Sudden increases in the short wavelength ultraviolet and X-ray emission from the Sun have been followed after a few days by a shift of the atmospheric circulation toward a pattern with definite glacial characteristics. In our case the effect must be catastrophic, for the energy deposited in the upper atmosphere is of the same order as the gravitational binding energy of that part of the atmosphere above 60 km. It is also of the same order as the total kinetic energy of the atmosphere. Thus, we can expect that the entire atmospheric circulation system will be profoundly modified. This will undoubtedly have disastrous short term effects with many storms of extreme intensity generated.

Willett has speculated that climatic changes in general, and the ice ages in particular, are the result of significant variations of the ultraviolet emission of the Sun. The variation under discussion here is of a short duration, but because of its extraordinary intensity it may have long term (\sim years) effects through a change of the albedo resulting from the formation of very high altitude ice clouds, or the alteration of the greenhouse effect due to the disruption of the ozone layer and the general large scale mixing of the atmosphere. Long term effects seem to be predominantly of a kind that produce increased storminess and lowering of temperatures over much of the Earth.

These effects are not necessarily unique to a supernova explosion. An intense source of high energy radiation is all that is required. Another possibility is an anomalously large solar outburst.

Detailed discussions of varying populations are omitted here.

In summary, the biostratigraphic record does not provide compelling support for considering global regressions of epicontinental seas or long term climatic trends as causative of the extinctions at the close of the Maestrichtian. It does suggest that the extinctions were of unusual magnitude and geologically brief duration, and may have been accompanied by a thermal drop. Eroded surfaces capping marine Maestrichtian sediments in stable tectonic areas may have been produced contemporaneously with the extinctions.

The biota of the Earth, which had not experienced widespread rigorous conditions for perhaps a hundred million years, probably would not have adjusted to the sudden onset of cool conditions as well as the modern biota. The disturbance of thermal stratification in the oceans by initial atmospheric turbulence, followed by several years of depressed temperatures, would dampen primary production in the oceans, concomitantly exterminating many forms in higher tropic levels. Atmospheric turbulence in conjunction with normal tidal currents may have results in the erosion of bottom sediments in many areas, thereby accounting for the widespread occurrence of a paraconformity separating Maestrichtian and Danian sediments in otherwise complete stratigraphic sections.

The supernova theory does not conflict with the record of extinctions at the Cretaceous-Tertiary boundary as at present understood. It has merit in that its predicted effects can be compared to the record to a greater extent than some other theories of mass extinction.

Cohen first summarizes the abundant evidence for widespread extinctions of various animals in recent geological history admitting that terrestrial catastrophism is one possible cause, he concludes with a discussion of extraterrestrial radiation, possibly from a supernova, as a potential agent of extinction. This is a long article, and only those paragraphs summarizing important data are reproduced here.

We like to think of North America, before the coming of civilization, as a natural paradise. It was more like an animal disaster area. Remember the song which describes the West as the place, "where the buffalo roam and the deer and the antelope play"? When from 1804 to 1806 the Lewis and Clark expedition traveled across the continent, the men were astounded by the buffalo (more properly bison). Zoologists are astounded too, but for other reasons. There is something unnatural about the picture. Why an estimated 50 million bison, one species of antelope and a few species of deer? What happened to all those other large animals? The land was fertile and capable of supporting many different kinds of animals, yet they had all disappeared. Some 70 percent of all native North American mammals with an adult body weight of 100 pounds or more died out during a 1,000-year period at the end of the Pleistocene.

Nor was this wave of Pleistocene extinctions limited to North America. It struck with varying degrees of severity throughout the entire world. Think about modern South America; for all its tropical jungles, the continent contains very few large animals. But 10,000 years ago there were a lot of them. Glyptodonts, toxodonts, macrauchenia and a host of strange creatures that most people have never heard of once populated South America.

Europe and Asia were also hit, although the extinctions were not as massive as those in the New World. Camels and horses which had actually evolved in North America and then died out there lived on in Asia. But mammoths and mastodons, several species of rhinoceros, the giant stag with 80 pound antlers and many other large animals failed to survive.

At first glance Africa with its wealth of large animals looks as though it escaped the wave of extinctions. The impression is incorrect. Although whatever it was that struck the great mammals dealt only a glancing blow to Africa, it still knocked out 40 percent of the large mammals.

In 1866, Alfred R. Wallace, the man who along with Charles Darwin first systematized the theory of evolution wrote:

"We live in a zoologically impoverished world, from which all the hugest, the fiercest, and strangest forms have recently disappeared. . . . yet it is surely a marvelous fact, and one that has hardly been sufficiently dwelt upon, this sudden dying out of so many large Mammalia, not in one place only but over half the surface of the globe." If Wallace had known what we know today he probably would have changed his statement to read, "Over the entire land surface of the globe."

EBE-004 THE GREAT EXTINCTIONS

Anonymous; Pursuit, 2:33-35, April 1969.

What follows is a witty essay (probably written by Ivan T. Sanderson) on the question of "crises in the history of life." It is hardly a "source document" but is presented rather to illustrate a biologist's view of some geological problems.

It is a real pleasure to report on this as it is wholly pragmatic, concerns recorded facts, and is altogether in the realm of reality. Pleasure is also occasioned by the absence of kookery though we have to admit that there is a quota of the usual imbecility overlarded with not a little misinterpretation. This matter is also most extremely interesting from another point of view, being as it is, a near classic case of what we have come to call a cross-over in that it has most pronounced chemophysical as well as geological aspects, and even cosmological and astronomical links, together with an anthropological implication. We present it under the general heading of biology for two reasons. First, this is the way it has been set out in current scientific literature, and, second, because we are going to concentrate on its biological aspects.

Last year, and starting early in January—see *Science* for the 26th January, 1968, Vol. 159, page 421—a considerable debate was initiated upon a very old question by the publication of an abstract by Messrs. K. D. Terry of the Department of Comparative Biochemistry and Physiology of the University of Kansas, and W. H. Tucker of the Department of Space Science of Rice University of Houston, Texas, in that periodical (*Science*). This was entitled:—"Biological Effects of Supernovae". There were numerous come-backs from many sources, which were published both in subsequent issues of *Science* and elsewhere, ending with one of the great Dr. George Gaylord Simpson's classic evaluations. And it is this that we will discuss primarily herewith.

For the benefit of those not specifically interested in palaeontology, or conversant with this field, we should explain that Dr. Simpson is not only the dean of that whole department of knowledge but is in just about every other way a captain of true science, a commander of erudition, and a positive commodore of literate expression. For our money you can take all the literary lights of American, British, and other current forms of "English" and toss them into either the etymological or epistemological trashcans. Further, he writes so that anybody can really understand what he is saying even on highly technical scientific matters. Also, unlike so many so-called experts, he really knows what he is talking about. It is his comments on this matter that we wish to present. But, first, a brief statement of what this is all about.

Palaeontological history as it has been pieced together since the commencement of the proper study of fossil life forms a little over a century ago, has clearly displayed a sort of cyclical progress, in at least one respect. This is the comparatively (from the point of view of geochronology) sudden appearances and disappearances of the larger groups of life forms; moreover, those mass disappearances seem to have more or less coincided with appearances, or upwellings, of newer and higher types of organisms. Four of these sort of changeover periods are recognized:—(1) at the beginning of the Cambrian, (2) at the end of the Permian, (3) at the end of the Cretaceous, and (4) at the end of the Tertiary, namely, during the so-called Pleistocene that immediately preceded the present. At the first change-over, the major types of backboneless animals appeared and gave rise to the fishlike; at the second, terrestrial forms, like the amphibians and then the reptiles, came on the scene; at the third, the mammals, birds, and flowering plants suddenly "flowered", while the majority of the previously dominant reptiles vanished; at the fourth, a considerable number of mammals became extinct and man got going as a quantitatively dominant form. The question that has always been asked has been—Why?

All manner of suggestions have been put forward, and this theory is only the most recent. It comes from the astronomers and astrophysicists. In a nutshell, it suggests that the extinctions, as well as the sudden outbursts of new

types, are presumably due to mutation and might have been caused by the type of exploding stars called supernovae, which the advocates of the theory endeavour to show should have occurred within a certain distance of this solar system, at set periods, and with peaks of individual intensity on just about the periodicity of these changeovers in the dominant life forms of this earth. The suggestion was, further, that deleterious radiations (particularly various cosmic rays) would arrive massively over comparatively (or actually) very short periods, and might so adversely affect some creatures as to cause their extinction, while so stimulating others that they went into wild mutation, proliferation, and numerical multiplication quantitatively. Then the argument began.

First, the cosmologists, astrophysicists, and astronomers had their innings by questioning those aspects of the theory and its foundations that fell within their provinces. Then the biologists got in the act, ending with a brilliant survey and critique by Dr. G. G. Simpson in a letter to Science which was published in their 4th October, 1968 issue, Vol. 162. In this the author put forth his usual string of utterly logical observations which showed that even if said deleterious radiations did hit this earth they would more likely have done so spread over a considerable time, even geologically speaking; while he presented equally cogent reasons why no such outside influences are really needed to explain the rise and fall of the major taxa of both plant and animal life on this planet. However, even this masterful analyst made some strange inferences; notably by combining two distinct types of extinction—that of groups of forms of familial or higher order, and that of a number of specific forms (in individual masses), such as the mammoths during the Pleistocene. These two processes need not necessarily be the same, though the causes of latter could have been one of the methods by which the former was achieved.

No more satisfactory explanation of or for the Pleistocene individual extinctions has been given than has been for the great taxas, disappearances. For instance, there is absolute evidence that many of the former were catastrophic (though intermittent) in that almost countless numbers of individuals of various species of all ages are found fossilized, or partially preserved in arctic muck, in vast aggregates, but most often not in situations where they might have accumulated over the years, by some such cause as floods. There are equally massive accumulations of more ancient forms, such as dinosaurs, fishes, shellfish, and other aquatic forms but there are several alternate and ready possibilities for these. There is thus considerable reason for supposing that the two types of extinction are not the same.

There comes then the matter of the opposite of extinction—namely, creation. And here a remark made casually some years ago by an engineer on being shown a series of fleshed-out reconstructions of extinct mammals that so suddenly appeared at the beginning of the Tertiary Era, as if ready made, and just after the equally sudden disappearance of the so-called dinosaurian reptiles, keeps repeating itself. He took a long look and then said simply—and with particular reference to these lumbering beasts "But those look like radiation-induced mutations".

There comes finally the very sticky problem of what stratigraphists among geologists call "unconformities". This means one strata of a sedimentary rock type, lying upon another totally different one of obviously much earlier age, but with no zone of blending between them, as displayed by their contained fossils or anything else. Such unconformities are attributed to the older of the formations having been elevated and their topmost layers eroded before sinking again under water where an entirely new set of sediments could be laid down on top of them. Such time-breaks occur all over the world between just about every group of strata and also, of course, between most formations, but there are some unconformities that, age-wise, seem to be universal. The most notable

of these is between the uppermost (or youngest) Cretaceous deposits and the lowest (or earliest) of the Palaeocene which lies at the bottom of the Tertiary. Nowhere yet discovered are the bones of late dinosaurs found associated with the earliest tertiary mammals. (Of course, there were mammals during the Cretaceous period, and many large reptiles like the crocodilians that are actually relic, dinosaurs in the general sense, have lived on through the Tertiary until today.)

Having always been both intrigued and mystified by this, we once wrote to Dr. Simpson on the subject and were the recipients of one of his remarkable letters. (How this scientist finds the time to read practically everything that is published and not only in his own bailiwick, and also answer letters from outsiders is one of the greater mysteries of life!) This ripped apart all the arguments upon which we had based the particular enquiry in our letter and thus put a major slice of tectonics, geochronology, and stratigraphy on a sounder basis. However, it included the bland and positive statement that there is no universal unconformity between the Cretaceous and the Tertiary.

Perhaps this was a matter of mere semantics, and Dr. Simpson was referring to geologic nonconformity, in that certain strata are alleged to have been found, and particularly in southern South America, that do seem to blend upwards, one into the other. However, the biologic unconformity is absolute, and worldwide, even if it may not be chronologically precise all over. Thus, we are still left with the question: Why did whole groups of animal life just vanish, while new ones so suddenly sprang into being, or proliferated so rapidly and enormously? Further, and even more questionable, is why, for instance, did all dinosaurian-type reptiles, both great and small and the aquatic lacertilians known as Mosasaurs, vanish, while the crocodilians, the rest of the lacertilians, and more so the chelonians (or turtles) and the little Tuatara, both of which antedate the dinosaurians, survive? And, conversely, where in the heck did such enormities as the vast herds of primitive ungulates spring from at the very beginning of the Tertiary, while only a few inches of sediment were being laid down? THERE IS A VERY REAL TIME GAP HERE.

All in all, it would seem that some outside influence is called for, and the most likely explanation for this might indeed be radiation. So, let us keep our eyes on these astrophysicists.

Why such a massive subsection on the mammoth problem? The answer is that the mammoth carcasses found around the shores of the Arctic Ocean along with the associated muck with its heavy burden of organic remains are considered to be key evidence that the earth was visited by widespread catastrophism in comparatively recent times. Of course, uniformitarians interpret the same evidence otherwise, as several of the following articles will prove. An important skirmish occurred in the late 1800s between the catastrophists and well-entrenched uniformitarians when Henry Howorth published his famous "The Mammoth and the Flood." The arguments were tempered and rational compared with the upheaval over Velikovsky's catastrophism of the 1950s. The battle is still joined.

EBM-001 THE MAMMOTH AND THE FLOOD

Anonymous; Nature, 37:123-125, December 8, 1887.

Nature's review of Howorth's famous anti-uniformitarian volume is well worth re-printing in these days of resurgent catastrophism. In 1887, Uniformitarianism had become dominant, but Howorth was treated kindly compared to Velikovsky.

The Mammoth and the Flood: an Attempt to Confront the Theory of Uniformity with the Facts of Recent Geology. By Henry H. Howorth, M. P., F. S. A. (London: Sampson Low and Co., 1887.)

Mr. Howorth's book is not disproportionate to its subject. But even as the mammoth it had a small beginning. It saw light as letters in Nature. It cast its swaddling-clothes at the British Association. Grown larger, it took passage on board the Geological Magazine, and, as some thought, threatened to swamp that useful but far from bulky periodical. Now, with body and tusks alike full-grown, it comes forth to champion cataclysm and scatter the uniformitarians.

The book consists partly of facts, partly of theories. The one part is separable from the other, though of course sometimes the facts are regarded in the light of the theories. We will endeavour in our notice to keep them apart. The first chapter of the work a little reminds us of the hors d'oeuvre which sometimes precedes a banquet. Appetizing bits, dainty but miscellaneous—the etymology of mammoth, and its identity with behemoth; griffons and their claws; fossil unicorns; dragons' bones; Indian fabulous beasts; stories of giants, and their bones: with such subjects is the reader's palate stimulated. The next chapter gives a history of opinion on the subject of the remains of the mammoth and the woolly rhinoceros. The author then discusses the abode and range of the mammoth in Asia. He considers it to have been limited to the tundras, which must at that time have enjoyed a climate far more temperate than at the present. Then comes an account of the various discoveries of carcasses, either of the mammoth or of the woolly rhinoceros, in Siberia; followed by the history of the same animals and their associates in Europe. The climate of Europe, when frequented by them, is next discussed, and the facts bearing on the extinction of the mammoth are enumerated, particular stress being laid on the evidence of caves and fissures. Palaeolithic man is next called into the witnessbox, and cross-questioned as to the cause of his disappearance. That he was exterminated by Neolithic invaders does not, to the author, seem a satisfactory theory. That he was a victim of the Deluge is a simple explanation. The Old World is now quitted for the New—the two Americas are examined. In each, at no distant time, huge mammals flourished; their remains are found under circumstances not materially different from those of similar quadrupeds in the Old World. So they also must have perished in like manner: the Deluge was not limited to Siberia nor to the Old World; it swept

alike over tundra and morass, over prairie and pampa; it inundated the New. Of course the West Indies could not escape; apparently no corner of the earth eluded the devastating waves, for Australia, Tasmania, and New Zealand tell the like tale of extinguished life, and sudden devastation. Lastly, there is the citation of historical evidence, in the form of brief summaries of the many variations of the widespread tradition of a universal deluge.

The facts, as indicated by the above statement—which is only a concise summary of the table of contents—cannot wholly be disentangled from the theories, in the light of which they are viewed and in proof of which they are ranged. Still, their value is independent of the theories: for the author has dealt with them in the spirit of an advocate, but of an honest advocate. If, indeed, Mr. Howorth can be accused of any forensic art, it is in this very pardonable respect—that the most is made of the opinions of geologists who have held views generally favourable to his own. Thus the unwary and but slightly scientific reader almost trembles before such a weight of authority, and is afraid to question an opinion favoured by so many lights of the heroic age of geology. But in citing authorities it must always be remembered that, unless it can be shown that all the important facts on which an induction is now founded were before them also, the value of their opinion is greatly affected, and it may even be comparatively small. Further, if satisfied on this point, we must inquire whether any, and, if so, what, alternative hypotheses had been presented to them. These preliminary considerations are often overlooked in quoting authorities, yet their importance cannot be disputed. The mind is greatly influenced by early impressions and by the hypotheses which it has accepted. In the multitude of facts we to some extent find what we seek, miss those of whose value we are ignorant, and without any conscious unfairness select those things which support the accepted view. Anyone who has had in the course of his life to reconsider and to modify an induction formerly maintained must be conscious that in this respect he has innocently erred. Probably, only a cantankerous-minded investigator wholly escapes this infirmity, and for him other snares are laid. Hence in this matter the testimony of even such men as Buckland, or Cuvier, or D'Archiac, is of small value, because not only has a vast store of new facts been acquired since their time, which have influenced or modified almost every branch of geology, but also because the widespread belief in a universal deluge and the virulent attacks made on geology by well-meaning but unthinking theologians had produced a natural readiness to welcome everything which seemed to harmonize with the Biblical narrative.

Mr. Howorth urges that a catastrophic occurrence is not excluded by a rational view of uniformitarianism—which position, we imagine, few would dispute in the abstract; but issue would often be joined as to which explanation were the more probable. He points out also that it is quite possible for a particular form of a tradition to be unhistorical, and yet for the tradition itself to have a true foundation, a remark which is certainly just, and which is sometimes forgotten. But, admitting these axioms, the asserted occurrence of any particular cataclysm is a question of evidence; and it is not enough for Mr. Howorth to show that his hypothesis explains some difficulties which exist in the other, unless he further prove that it is not only in accordance with a larger number of facts, but also does not create a new class of difficulties still more formidable.

Mr. Howorth's preface sounds no uncertain note, as the following extract will show:-

"The coral-insect (sic) raises the islands of the Pacific, and the fall of leaves in a tropical forest piles up deep black soil. These cases are no doubt cases of continuous change; but if we turn elsewhere we have to explain a very different state of things. The great gaping cliffs and sheer precipices of the Alps, the splintered pyramids of the Sierra Nevada, the canons of Colorado, the

huge dislocations of the strata, involving faults of hundreds of fathoms in extent, so near us as Durham. These have not the look of gradual changes."

We rub our eyes, and wonder whether the last fifty years have been all a dream. Here are dead and gone geological ideas in full vigour. We had thought that if there was one spot on earth in which catastrophe could not be invoked, where the uniformitarian could be in peace, it was the Colorado canons; and we cannot help thinking that if Mr. Howorth were a member of the English Alpine Club he would by this time have convinced himself that, whatever signs of ruin the Alps may afford, there are none of any vast catastrophe. It is therefore evident that Mr. Howorth's method of interpretation differs from that of geologists in general, and this must throughout the book be borne in mind by the reader. But Mr. Howorth is always rather a special pleader, ingenious sometimes, but generally inconclusive. Granting that occasionally he contrives to give a smart rap to the irrational uniformitarian (for such a person does exist) and hits upon a defect in an hypothesis, he straightway goes on to propose a solution involving greater difficulties. In a brief notice it is impossible to deal with particular instances, but some general indications may be given. The carcasses of mammoths are found embedded in ice in the north of Siberia. It is admitted that, from their state of preservation, they must have been frozen up very shortly after death, and have so remained ever since. There are no doubt considerable difficulties in attributing their transport to a river flood, as Mr. Howorth points out; nevertheless, when we remember the peculiarities of the Siberian rivers, and that in a cold region a carcass would be slow to decompose, for the flesh might freeze before it ceased to drift, these do not seem insuperable. Mr. Howorth, as an alternative, offers the hypothesis of a deluge, followed by a sudden change of temperature, but, apart from the difficulties attending the former part of this, by what physical or astronomical catastrophe does he account for the latter? Wisely, he makes no attempt to indicate this.

Again, in speaking of the contents of eaves, Mr. Howorth constantly lays stress upon the indications of the action of running waters, and upon the absence of any such disturbing agent at the present time. But he forgets that even followers of Lyell would admit that at no very remote epoch the climate of England was different, the rainfall was heavier, the streams were all bigger, nay, that a cave itself is symptomatic of running water, which in most cases would gradually forsake its old course. The stream which made Clapham Cave still runs concealed, hard at hand, through the limestone rock, and not so long ago, after a downpour on Ingleborough, welled up into its ancient channel. We wonder whether Mr. Howorth has ever seen what the fall of 4. inches of rain in a single night—no unprecedented case—can do even in our English lowlands. Such a downfall would turn many a dry fissure, small as its drainage-area might be, into a running stream. Mr. Howorth, in combating uniformitarians, seems to overlook the variations and catastrophes on a small scale (compared with the bulk of the earth) which everyone who has sat at the feet of Lyell accepts as axiomatic.

It would have been more politic had Mr. Howorth contented himself with local deluges; but no, his destroying waves must pass over the whole earth. What is to generate these destructive waves, what multiplication of a Krakatau catastrophe is needed, how many cubic miles of mountain summit must fall into the sea, or of ocean bed leap up into the air, he forbears to tell us. Here, after a laborious scrutiny of facts, the reader is refreshed by a use of the imagination.

We leave a host of minor difficulties unnoticed for want of space, such as the occurrence of erratic blocks in positions of unstable equilibrium, the relation of drifts, supposed cataclysmal by the author, to the valleys in which they occur, the escape of apterous birds like the moa and the dodo, and the like. We must part from the book by saying that it exhibits great industry in the collection of

materials——so that it will long be valuable as a work of reference——with a curious want of mental perspective, and a misapplied ingenuity of reasoning.

See also the following letters pertaining to this review.

EBM-002 "THE MAMMOTH AND THE FLOOD"

Howorth, Henry H. ; Nature, 37:200-201, December 29, 1887.

In the notice which you have given of my book, which you are good enough to say is, apart from its theories, a valuable work of reference, I should have been more gratified if you had devoted a little space either to stating my arguments or to refuting them, instead of indulging in a rhetorical wail over my backsliding from the orthodox ways of uniformity.

The theories for which I am responsible have been accepted by so many men in the first rank in science in both hemispheres that I am naturally anxious to have them seriously and severely discussed, and I think your critic would allow that I have justified my hope that this will be the case by converging upon my inferences an unusual array of facts.

It was assuredly quite time that someone who disbelieves in "authority in science" should raise a strong protest against the extravagant position which the English school of geology has taken up on this question of uniformity, an extravagance of which students in other branches of science are hardly aware.

The head of the Geological Survey in this country, speaking not long ago with all the authority and responsibility which surround a President of the British Association, committed himself to the following statement:—"From the Laurentian epoch down to the present day, all the physical events in the history of the earth have varied neither in kind nor in intensity from those of which we now have experience."

This was not the opinion of an irresponsible and eccentric student, but of the official mouthpiece of English geology, and with one notable exception——namely. Prof. Prestwich——it has remained, so far as I know, without protest or repudiation, while Prof. Prestwich himself has been treated as a heretic for the views he has so courageously and ably maintained.

My book is meant to challenge the doctrine of uniformity as generally held by English geologists, and which as held here is largely repudiated both in America and on the Continent.

In regard to its many arguments, I cannot defend them in a letter, but I can shortly examine the only one to which your critic directs attention, and which happens to be a very crucial one.

This is the explanation of the existence of a series of mammoths buried in the tundras of Siberia, throughout its entire length, with their soft parts intact. This fact, which has been known for a century, compelled Cuvier long ago to adopt a conclusion which I have simply accepted and enlarged. I state it shortly in the following extract from my work:—"The facts compel us to admit that when the mammoth was buried in Siberia the ground was soft and the climate genial, and that immediately afterwards the same ground became frozen, and the same climate became Arctic, and that they have remained so to this day, and this not gradually and in accordance with some slowly continuous astronomical or cosmical changes, but suddenly and per saltum." I also argue that the only way I can explain the existence of a chain of such carcasses buried many feet

deep in continuous beds of gravel and clay is by the operation of one cause only, and that a flood of water on a large scale.

Your critic, who I can hardly think has read the part of my book dealing with this issue, says that the carcasses are found in ice. The fact is, they are never found in ice, as the Russian explorers have so well shown. The reference to ice in the account of the discovery of the famous Adam's mammoth has been shown by Baer to have been altogether misunderstood, and nothing is more clear than that they are found buried deep in hard frozen gravel and clay.

Secondly, he urges a view which was generally held fifty years ago, but which has been completely dissipated by the elaborate researches of the Russian naturalists, especially the geologist Schmidt, and which I quote at length—namely, that the carcasses have in some way been floated down by the Siberian rivers and buried in their warp. As Schmidt shows, the Siberian rivers make no deposit, either in winter or summer, which could cover in a mammoth. Nor are the mammoths chiefly found near rivers, but on high ground out of the reach of rivers. When they occur near the rivers, it is generally on the head streams, which could not float such carcasses.

Surely, in criticizing my view of a problem which has been the crux of almost every serious student since the days of Cuvier, your critic might have noticed these now elementary facts. It is not fair to me or to your readers to deal with this difficult question as if it could be settled by a casual reference to causes long ago discarded by such authorities as Brandt and Baer, Schmidt and Schrenck.

I am anxious beyond measure to meet with some criticism that I can reply to, and shall not shrink from the issue being tried by the severest tests.

What I complain of, and others more important than myself share my opinion, is that the only answer forthcoming from uniformitarians to test cases like the one above referred to is, ostrich-like, to put their heads in the sand and to cry out, "Since we are committed to Lyell's theory, it is useless to quote facts against us." This may have done in the fifteenth century, but it will not do now when so many critics are abroad.

May I presume to invite a discussion in your paper on this most interesting question? I cannot forget that it was in your pages I first raised it many years ago. (Henry H. Howorth)

In regard to the first part of Mr. Howorth's letter, I must remind him that it was admitted in my review that such a being as an irrational uniformitarian did exist, and was duly smitten in his book.

In regard to the occurrence of mammoth carcasses (not skeletons), I wrote of ice with some hesitation, knowing alleged cases to be open to question, but I mentioned it, because, in my opinion, it would be the most difficult to explain, and the strongest case in favour of Mr. Howorth. Where the carcass is preserved in clay or gravel the difficulty is less. All that seems needed is a flood of rather exceptional character, carrying the dead beast rather far north; then, if this happened at the right season of the year, the body might be buried by other floods before decomposition set in (the temperatures might be always low, though sometimes above 32°F.), and so the body might escape unrotted, until it was finally well entombed. My position was that, though this explanation of the escape of a carcass from destruction, under circumstances not very different from the present, was not easy, the explanation of such a series of catastrophes as Mr. Howorth demanded was much harder. The grounds of this opinion cannot of course be stated in the limits of a letter, nor can I discuss seriatim the cases which he cites.' So far as my memory serves me (I am writing at a distance from any scientific library) they are not so universally favourable to his view

as is stated in his letter.

The remainder of Mr. Howorth's letter is open to the charge which he brings against the review, of being merely rhetorical. Quis tulerit Gracchos de seditione querentes? (Your Reviewer)

EBM-003 "THE MAMMOTH AND THE FLOOD"

Howorth, Henry H. ; Nature, 37:295, January 26, 1888.

The question raised in my previous letter is too important and is being too widely discussed to allow me to let it go by default, and as it has a certain freshness I cannot help thinking that it will prove interesting to many of your readers.

Your critic disposes of Sir Andrew Ramsey in a very unceremonious fashion. To describe the head of the Geological Survey, and the former President of the British Association and the Geological Society, as an irrational uniformitarian is to get rid of my attack in a very simple way. Surely some of his scholars or some of his subordinates will have a word to say for their late chief, and, if they cannot maintain his position, will offer some alternative. To the great mass of scientific men who are not geologists, teaching from such a source is naturally accepted as authoritative.

To pass on, however. Your critic speaks of my invoking a series of catastrophes to explain the difficulties surrounding the extinction of the mammoth. This is most inexplicable to me, and points to his not having read my book at all, which was neither fair to you nor me. My book is a perpetual protest against such a series of catastrophes, and an argument in favour of one catastrophe only. May I quote one statement among others?

"If we are to summon some normal cause not now operating for these facts, it certainly seems more reasonable that, with effects so completely alike over such a wide area we should summon one cause, and not several, and attribute the aberrant conditions showing so much uniformity to some uniform impulse. Here, again, the burden of proof is upon those who deny this view, and treat the remains not as the result of some widespread catastrophe, but as evidence of as many catastrophes as there are skeletons.

"It would be as unreasonable to invoke a separate storm and a separate date for the death of each one of the myriads of razor-bills and guillemots that strewed the western coasts of Britain on a fatal occasion a few years ago, and whose remains were all fresh and in the same condition, as to do the same for the myriads of fresh skeletons of mammoths, rhinoceroses, bison, &c., in Siberia or in Europe. These debris of a former world have every sign that they formed parts of a contemporaneous fauna destroyed at one time, and are not the wreckage of centuries of deaths."

I now come to what is more important; namely, the theory which your critic resuscitates, after it has been given up by all the Russian inquirers, save one, for many decades—namely, the notion that the mammoths have been floated by the rivers from some undefined land and buried by river action, where they are now found.

Dr. Bunge, who has recently returned from a protracted residence on the Lower Lena, and has described his researches in detail before the St. Petersburg Academy, tells us expressly that mammoth remains are found very seldom indeed in the delta of the Lena, and very seldom also near that river. It is in the higher

land separating the great rivers that the remains abound and especially, as Wrangell and others showed long ago, and as Bunge has recently confirmed, in the mounds and low hills of the tundra. When found near rivers, it is near the short rivers, like those of North-Eastern Siberia, or near the head streams of the Lena, the Yenissei, &c., which could not float such carcasses.

In the next place, Northern Siberia is not a country of mountains and small valleys, but a vast, continuous, nearly level waste covered with moss, called a tundra, diversified by mounds and rounded hillocks, and threaded here and there by rivers running in deep channels—rivers which are frozen fast for a large part of the year.

When the late spring comes, and the ice in the upper reaches melts, while that lower down is still locked fast, there is no doubt a considerable flood in the estuarine parts of the Obi and other rivers, but this is temporary and transient, and it only covers the low lands where mammoth remains are most infrequent. It never covers and cannot cover the higher land. There is not supply of water to do it. To cover the higher points where the mammoth and other remains abound would require such a supply as would put the whole northern part of the continent under water, and thus destroy all animal life there every spring flood. Even if we could postulate river floods of this kind as I have shown, quoting a most experienced geologist, Schmidt, the Siberian rivers deposit no warp that could cover in the mammoths as they are found covered in, by deep beds of clay and gravel, not when lying on their sides only, but when standing upright, as they have several times been found. They must have been covered in by more than two yards of deposit also in a single year in all parts of Siberia, since the ground melts to that depth in the summer, which melting would destroy their soft parts. Appeals to river-floods therefore involve appeals to transcendental causes which are obsolete in other sciences than geology.

Lastly, why is this river portage invoked at all? We have not merely the mammoth carcasses to account for, but the trees found with these great beasts still rooted, and the land and freshwater shells showing a different climate when he lived.

Where are we to bring these debris of a former life from? We cannot go outside of Siberia; for the mammoth, so far as we know, has never been found in Asia outside that province. We cannot bring the mammoths found in Kamchatka, and the peninsula of the Chukchi, and the Liachov Islands (which are 150 miles from the mainland), from Central Siberia. Again the remains are very infrequent there compared with their abundance further north, while the mammoths from the north and south of Siberia can be discriminated. There is no sign of rolling on the bones, and the epiphyses are still attached. Evidence of every kind converges therefore upon the conclusion that the mammoths lived and died where their remains are found, and the problem that has to be faced is, how they were exterminated simultaneously from the Obi to Bering Straits, of all ages and sizes, and mixed with various incongruous beasts; how they were buried in the hillocks and high ground under vast, undisturbed, and continuous beds of gravel and clay; and how, lastly, their flesh was subsequently preserved. If all this can be explained without some appeal to the forces I have invoked, then one factor out of many in my argument can be answered. If not, it is no use going to Wonderland for hypotheses which only arouse ridicule among students of those sciences which claim induction for their basis. I am most anxious for an answer.

EBM-004 THE MAMMOTH AND THE FLOOD

Anonymous; Saturday Review, 65:52-53, January 14, 1888

This review of Howorth's book tells much more about its contents than the review in Nature (EBM-001), and Howorth is faulted mainly for his grammar

Mr. Howorth treats the Bible narrative as only one out of many testimonies to the Universal Deluge. The conclusions which he formulates are six—(1) that a great catastrophe took place at the close of the mammoth period, which overwhelmed that animal with its companions, over a very large part of the earth's surface; (2) that this catastrophe involved a widespread flood of water, which not only killed the animals, but buried them; (3) that it was accompanied by a great fall of temperature in Siberia; (4) that this catastrophe took place when man was already occupying the earth, and constitutes the gap which is almost universally admitted to exist between Palaeolithic and Neolithic man; (5) that the primeval Flood which occurs in the traditions of so many races may probably be identified with this catastrophe; (6) that, widespread as this Flood was, considerable areas escaped, and from them man, animals, and plants spread out again and reoccupied those districts which had been desolated. This is a startling programme, with far-reaching issues, which will no doubt provoke plenty of that keen criticism which Mr. Howorth invites. In the work before us the problem is approached from the archaeological and palaeontological side only, but we are glad to learn that it is shortly to be followed by a second, dealing with the geological aspect of it. For the present, therefore, we have only half the evidence—that to be derived from the narratives of travellers and explorers—but this has been collected with extraordinary industry, and, so far as we are able to judge, with complete fairness. We cannot say that we fully agree with Mr. Howorth in his violent attack on "uniformity," towards which, while speaking with invariable respect of Sir C. Lyell himself, he adopts a scolding and abusive tone unworthy of a scientific treatise. He seems to have set up an idol for the sake of smashing it; and we fail to find any difference in kind between the deluge of his imagination and those which have taken place in our own time—for instance, in Java and Iceland. But as regards the special thesis he has set himself to defend, that water was the agent which destroyed the mammoth and its companions, we must admit that he has made out a very strong case. This we will try to state as fairly as we can, but it is no easy task to detail in a limited space even the leading points of an argument which depends on a multitude of minute facts, gathered from the whole surface of the globe.

The existence of ivory in Siberia in a sub-fossil condition, but still sufficiently durable to be used for all the purposes to which recent ivory is applied, has been known since the middle ages, and formed one of the earliest exports from Siberia to China. The very name given to the gigantic creature which produced it, Mammoth or Mammont—probably a corruption of Behemoth—was introduced by the Arab traders who initiated the traffic in fossil ivory in the tenth century. It was not, however, until the middle of the eighteenth century that the trade became considerable. In or about 1750, Liachof, a Russian merchant, discovered vast stores of elephant tusks and bones in the northern districts of Siberia, and especially on the islands off the mouth of the Lena, which have since borne his name. The ivory brought thence, says the traveller Wrangell, "is often as fresh and white as that from Africa." Since Liachof's discovery it has been computed that the tusks of at least twenty thousand mammoths have been exported, while an even larger number are too much decayed to be worth removal, and others are so large that they have to be sawn up on the spot where they are found. These buried hecatombs of elephants abound throughout the frozen soil of

Siberia, but they are more numerous the further we advance northwards, and most plentiful of all on the islands above named and in those termed New Siberia. More remarkable still are the mammoth mummies—several of which have been disinterred, whole carcases not unfrequently standing upright in the frozen soil, with their flesh "as fresh as if just taken out of an Esquimaux cache or a Yakout subterranean meat-safe." The most widely known of these is that discovered in 1806 by an English botanist named Adams, and the skeleton, or such parts of it as could be recovered—for in the interval between part of it being laid bare and the information reaching Adams wild animals had preyed on the flesh and carried off many of the bones—is now in the museum at St. Petersburg. Carcases of rhinoceros have also been found under similar conditions. It is agreed on all hands that these bodies must have been submitted to "continuous congelation without a break" ever since they died; in other words, the catastrophe which slew them must also have buried them and so changed the climate that their flesh has been preserved to the present day. Mr. Howorth shows, we think conclusively, that the animals lived in Siberia, and were not transported thither after death from some other place. The bones show no appearance of detrition; the largest numbers and those in the finest condition are found at a distance from the rivers; and, further, their numbers decrease as we go further south. Again, though the climate could not have been as cold while they were alive as it is now; it is evident that it was by no means a warm one; for there is ample evidence that they were protected by a thick coating of hair and wool. Collateral proof of a change in the climate is afforded by the debris of trees—"large stems, with their roots fast in the soil"—found in places where no vegetation, save lichens, grows at present; and that the elephants fed on these trees may be conjectured partly from their long recurved tusks, which would be peculiarly useful in pulling down branches, partly from the analogy of the rhinoceros—for the contents of a mammoth's stomach have not as yet been observed. In 1876, however, the cavities of the teeth of a rhinoceros yielded fragments of the leaves of coniferous and other trees.

After discussing very fully what may be termed, if we may coin a word, the death-history of the Mammoth in Northern Asia, Mr. Howorth passes to Europe, and attacks the curious question of the fauna of the Mammoth period, which appears, from its remains, to have been composed of animals the most dissimilar in structure and habits; and he proposes an ingenious hypothesis to explain how it came to pass that polar-bears, lemmings, marmots, and reindeer were contemporaneous with hippopotamous, lion, and elephant. Without going into details, his contention is that portions of Europe—e. g. Switzerland and Scandinavia—were then icebound and sterile, that the levels immediately below the high mountain-ranges were inhabited by mammals and birds now living in high latitudes and mountain-fells, and that the river-valleys, sheltered by dense forests, were warm and luxuriant, and afforded a congenial shelter to animals now confined to the tropics. It is hardly necessary to add that his hypothesis does not postulate that the animals in question lived together as a happy family, but that within a comparatively short distance of each other animals were to be met with which now require wholly dissimilar climatic conditions. By what agency, however, were these animals brought together, so that we find in the same pit the bones of the whole of the above-mentioned fauna—young and old together (a very important point)—nearly always unworn, and frequently with the limb-bones in juxtaposition? Mr. Howorth rejects the usual theories, and pleads for "rushing water on a great scale." This agency would drown the animals, and yet would not mutilate the bodies. It would kill them all with complete impartiality, irrespective of their strength, age, or size. It would take up clay and earth, and cover the bodies with it. . . . The occurrence of immense caches, in which the remains of wild animals are incongruously mixed together pell-mell,

often on high ground, seems unaccountable, save on the theory that they were driven to take shelter together on some point of vantage, in view of an advancing flood of water, a position which is paralleled by the great floods which occur occasionally in the tropics, where we find the tiger and its victims all collecting together on some dry space, and reduced to a common condition of timidity and helplessness by a flood which has overwhelmed the flat country. . . . In the present case all were overtaken by the water, tossed and tumbled together in a common destruction, and then covered thickly with a mantle of clay or gravel—a mantle, be it remembered, spread over immense areas, without a break external or internal, and in which we can find no traces of local disturbance, such as would be caused by any process of subsequent burying, and showing that bones and covering were laid down together.

In support of this theory of drowning he cites, among other facts, the rhinoceros found by Pallas, the head of which still showed "the blood-vessels and even the fine capillaries filled with brown coagulated blood"—a condition which is just what might be expected in an animal which died from drowning; the position of many of the mammoth skeletons; and the curious fact that some of those in Siberia are standing upright, with their tails turned to the south, as though the deluge had come from that direction. Water, again, he contends, would explain the presence of the Pleistocene mammals in caverns and fissures to which they could not have been brought by hyaenas, lions, or other beasts of prey.

The evidence afforded by the remains of our own species is marshalled by Mr. Howorth with great dexterity in support of his theory. Those who have studied this question most carefully divide *primaeval* man into *Palaeolithic* and *Neolithic*; and it is agreed that the former race was contemporaneous with the Pleistocene fauna and flora, the latter with modern wild animals. The former was a race of hunters, who dwelt in caves; the latter an agricultural people who built houses (not uniformly, but occasionally), kept domesticated animals, and possessed a knowledge of the arts of weaving and making pottery. The remains of the two races are never found together. The French and Belgian archaeologists are particularly emphatic in pointing out the distinct line of demarcation with separates them; and our own distinguished geologist, Mr. James Geikie, argues on the same side. "The implements of the one period," he says, "are never found commingled with those of the other, nor do the characteristic faunas of the two ages ever occur together in one and the same undisturbed deposit." In certain cases, for instance, a layer of barren loam marks the gap between the two deposits; in others a mass of stalagmite. The culture of the later period, as was pointed out long ago by M. Lartet, could not be derived from that of the earlier. A striking illustration of this gap, or interval, is afforded by the history of the horse. The horse was common everywhere in Pleistocene times, but in France, Belgium, and Switzerland it is absent from Neolithic caves and lake-dwellings. On the other hand, it occurs abundantly in corresponding places belonging to the later Bronze age. The obvious inference is that it was reintroduced by a later culture. Again, though common in Pleistocene deposits in Algeria, it is absent from the older Egyptian monuments; in America, where it abounded in the same strata, it had become extinct when the Spaniards occupied Mexico; and Mr. Howorth might have added that the Indians worshipped as a divinity a sick horse left behind by Cortes in his famous expedition to Honduras. Various expedients have been resorted to to explain the cause of an effect so universally recognized; but Mr. Howorth is unquestionably right in insisting that a true explanation must account for the complete disappearance of one type of man, with a distinct fauna and flora, and the reappearance of another type with a new and equally distinct fauna and flora, but without any intermediate forms to link the two together. An immense flood, which M. Dupont had already invoked to explain similar phenomena in Belgium, is no doubt a "*raison suffisante*."

Here Mr. Howorth closes his case for the Old World, and proceeds to "test the problem" in North and South America, the West Indies, and New Zealand. Over these regions, however, though the chapters dealing with them occupy nearly half the volume, and form by no means the least interesting part of it, space compels us to follow him with a very rapid step. Throughout the American continent the great mammals—the Mammoth in the far North, the Mastodon and Megatherium in more temperate regions, and the Glyptodon, Toxodon, and Scelidotherium in the South—are found buried under conditions almost identical with those noticed in corresponding cases in the Old World. The skeletons of Mastodons especially are found entire, the contents of their stomachs lying still intact within their ribs, young and old together, and often in a position which implies that the animal was swimming when it perished. Again, the "whole area of the Pampas is one wide sepulchre"; the bones found therein are fresh, filled with animal matter, and with no appearance of detrition. Here, however, the problem is complicated by the fact that, while the large mammals have perished, the smaller have survived. To what cause are we to ascribe the destruction of the huge Glyptodon and the preservation of the small armadillo? "It is impossible," as Darwin puts it, "to reflect on the changed state of the American continent without the deepest astonishment. Formerly it must have swarmed with great monsters; now we find mere pigmies." But, after stating the various theories suggested to account for these facts, the great naturalist discards them all, and leaves the problem unsolved. D'Orbigny, on the other hand, whose explorations in South America give him a right to speak and to be listened to, is less cautious, and believes that in the upheaval of the Cordilleras we may find the cause of which we are in search. This theory Mr. Howorth adopts; for says he:—"It explains how the huge unwieldy beasts and the animals living on the level plains were overwhelmed, while the smaller creatures—those with a more nimble gait or those living on places of vantage—escaped; and it not only explains the destruction of the animals, but their burial." The same catastrophe is made responsible for the formation of the West Indian Archipelago, and the destruction of the fauna, of which scattered fragments alone remain; while a similar convulsion is evoked to explain the phenomena observed in New Zealand, where "in the caves, on the mud-flats near the sea-shore, and on the turbary deposits, both of the North and South Islands, large collections of bones are found mixed together in utter confusion, as though a number of struthious birds of different genera and species, overtaken and driven together by a common peril, had perished in one general catastrophe." If we understand Mr. Howorth aright, he imagines that the flood which devastated New Zealand was partial in its operations, leaving behind a certain quantity of Moa-birds to be hunted, and finally extirpated, by the Maoris, whose legends respecting their existence he is disposed to accept. In a concluding chapter the evidence of tradition is accumulated, beginning, of course, with the Bible, but into this part of the subject we have no space to enter.

In the course of these remarks we have more than once praised Mr. Howorth for his industry. We wish we could extend our praise to his accuracy. It is true that he pleads, in extenuation of possible mistakes, "the double burden of bad health and too many other claims on time and leisure"; but neither sickness nor occupation can excuse the extraordinary carelessness with which his book is printed. We should have thought that an ordinary press-reader would have drawn attention to faults in grammar for which a schoolboy ought to be birched; and as for the quotations, many of which we have been at the pains of testing, it is a rare thing to find one that is correct. Even three lines from Lucretius contain two serious blunders. Mr. Howorth has yet to learn that accuracy in these matters can only be insured by comparing all quoted matter with the original text after his own work has been set up in type.

EBM-005 MAMMOTH GRAVEYARDS

EBM-005 THE NEW MAMMOTH AT ST. PETERSBURG

W., A. S. ; Nature, 68:297-298, July 30, 1903.

So much sensational literature exists describing the frozen Siberian mammoths that this matter-of-fact account is refreshing.

The new mammoth just mounted for exhibition in the Zoological Museum at St. Petersburg, is a triumph of the taxidermist's art. The frozen skin has been cleaned, softened, and prepared. The skeleton, and as many of the surrounding soft tissues as possible, have been carefully removed from its interior and preserved separately. The animal has been actually stuffed like a modern quadruped, and placed in the attitude in which it originally died. The skin of the head and the ears are artificial, copied from the famous old specimen obtained a century ago by Adams. A model of the base of the proboscis has also been added. The skin of the trunk and limbs, however, is nearly complete, only embellished in parts by the addition of a little wool and hair from other specimens; and some deficiencies are covered by the surrounding mount, which represents the morass into which the animal slipped. The well-preserved tail is especially noteworthy, and bears a large tassel of long black hair at its tip. The animal is a young male of rather small size.

The hopelessly-struggling aspect of this mammoth is very striking, and reproduces exactly the attitude of the carcase as it lay buried in the Siberian tundra. In fact, the chief value of the specimen depends upon the circumstance that it was scientifically disinterred, photographed at various stages in the excavation, and carefully preserved by the best modern methods. Great credit is due to Dr. Otto Herz, the leader of the expedition organised by the St. Petersburg Imperial Academy of Sciences, who undertook the arduous task of securing the carcase and transporting it to the Russian capital. His are the only photographs hitherto obtained of a mammoth buried in the tundra, and they throw important new light on the question of the conditions under which these large quadrupeds were destroyed and entombed. Some of Dr. Herz's photographs have lately been presented by Dr. Salensky to the British Museum, and two of them are reproduced in the accompanying figures.

The carcase in question was exposed by a landslip on the bank of the River Beresowka, an affluent of the Kolyma, in the Government of Jakutsk, in latitude 67° 32' N. The head was entirely uncovered, so that the toxes and other carnivores ate its soft parts, while the inhabitants of a neighbouring village removed a tusk. The Governor of Jakutsk, however, succeeded in keeping the remainder of the specimen undisturbed until the arrival of the expedition from the Academy. It was buried partly in ice, partly in frozen sand and gravel, and there was a sufficient covering of earth to prevent its naturally thawing.

According to the general report published by Dr. Herz, * he began to excavate the specimen from the front. In this manner he soon discovered the two fore limbs spread widely apart, and sharply bent at the wrist. Proceeding backwards on the left side, he unexpectedly met with the hind foot almost at once, and it gradually became evident that the hind limbs were completely turned forward beneath the body. Dr. Herz then removed the skull, and found the well-preserved tongue hanging out of the mandible. He also noticed that the mouth was filled with grass, which had been cropped, but not chewed and swallowed. Further examination of the carcase showed that the cavity of the chest was filled with clotted blood. It is therefore natural to conclude that the animal was entrapped by falling into a hole, and suddenly died from the bursting of a blood-vessel near the heart while making an effort to extricate itself. As shown by the recent researches of Dr. Tolmatschow, the ice surrounding the carcase was not that

of a lake or river, but evidently formed from snow. It is thus quite likely that the mammoth was quietly browsing on grassland which formed the thin covering of a glacier, and fell into a crevasse which was obscured by the loose earth. On this subject, however, much more information may shortly be expected, when Mr. Ssewastianow publishes an account of the geological researches which he made in the neighbourhood of the Beresowka last summer.

1 "Berichte des Leiters der von der kaiserlichen Akademie der Wissenschaften zur Ausgrabung eines Mammuth-kadavers an die Kolyma-Beresowka ausgesandten Expedition" (St. Petersburg Academy of Sciences, 1902).

EBM-006 FROZEN MAMMOTHS AND MODERN GEOLOGY

Farrand, William R.; Science, 133 729-735, March 17, 1961. (Copyright 1961 by the American Association for the Advancement of Science.)

This article should be contrasted with that of Ivan Sanderson which follows to see how different "camps" view the same evidence. In 1961, scientists were very wary of catastrophic implications—much more so than today. In any event Farrand presents an excellent review of the basic data.

Frozen woolly mammoths have perplexed both scientists and laymen during the several centuries since the first direct description of a frozen mammoth was recorded, in 1692. In the records of Digby, a well-known mammoth hunter, "the gods must have enjoyed many a hearty laugh over humanity's attempt to account for the remains of mammoths." One of the biggest obstacles to complete interpretation of the frozen mammoths was, and to a lesser degree is still, the lack of detailed knowledge of the distribution, geologic context, and age of the beasts. Tolmachoff wrote a very complete summary of the information available in 1929, but no comprehensive paper has appeared since that time, although many more geological data are now at hand.

In contrast to scientific efforts, a number of popular and quasi-scientific articles have appeared in recent years, in which fragmentary knowledge, folk tales, and science fiction are combined under the guise of verity—much to the chagrin of scientists and the confusion of the public. The most recent of such articles is that of Sanderson, who comes to the conclusion that the "frozen giants" must have become deep-frozen within only a few hours' time. Such a thesis, however, consistently disregards the actual observations of scientists and explorers (discussed below). Adding insult to injury, Sanderson proceeds to fashion a fantastic climatic catastrophe to explain his conclusions.

Information from diverse, mostly European, sources is summarized in this article to bring the subject of frozen mammoths up to date and at the same time to supply to scientists in general the information with which to refute the current quasi-scientific theories. Although the general ecology and range of the woolly mammoths is included, this article centers on the frozen representatives of the species and the special problems they present. All other species of mammoths, such as the Columbian, Imperial, and Jefferson mammoths, are entirely excluded from this discussion.

The subject of extinction is not discussed here because it is not a problem

peculiar to frozen mammoths but one that concerns other species of mammoths and many other large Pleistocene mammals as well. Let me say only that climate apparently did not play a direct role in the demise of the Siberian mammoths. Woolly mammoths were well adapted to extreme cold and to tundra vegetation—conditions which still characterize the area where frozen cadavers have been found. Furthermore, woolly mammoths lived in pre-Wisconsin and late-Wisconsin time, and this shows their ability to survive a glacial onslaught.

Description and Ecology. The taxonomic position of the woolly mammoth is rather well defined, although some controversy surrounds its generic name. Elephas prlmigenius Blumenbach 1799 has withstood many competitors throughout the years; it is found in much of the older literature and is still used in Europe. Currently, however, Mammuthus prlmigenius (Blumenbach) is used in North America and, accordingly, is used in this article, without any attempt to resolve the difference. However, histological examination of frozen mammoth bone from Alaska favors retention of the genus name Elephas.

Mammuthus prlmigenius (Blumenbach) was an imposing creature, standing as tall as modern elephants but with slightly different proportions. The Siberian mammoths—2.8 meters tall at the shoulders—were somewhat smaller than the average European woolly mammoths (3.2 to 3.9 meters tall); modern Indian elephants are 2.7 to 3.2 meters tall, and African elephants average 3.4 meters. The woolly mammoth differed from modern elephants in the following important features: (i) the mammoth's head had a conspicuous topknot formed by large sinuses and possibly lumps of excess fat (it is well shown in prehistoric cave drawings in western Europe); (ii) the mammoth had only four skeletal toes as compared to pentadactylism in other elephants; (iii) its body was covered, or nearly covered, with long coarse hair and thick underfur; under its epidermis, which was identical with that of a modern elephant, was a layer of fat up to 9 centimeters thick; (iv) the mammoth's tusks were larger and more curved than those of modern elephants, although not as curved as they are often depicted; Digby found in a collection of more than 1000 tusks that "not one tusk in ten forms a third of a circle, not one in twenty even a semi-circle"; and (iv) the slope of the back from shoulder to hip was greater in the mammoth than in modern elephants, and this was especially pronounced in the Siberian population.

The evolutionary development of Pleistocene elephants is rather well known; it is based mainly on dental characters (decrease in the size of dental plates and the thickness of enamel layers and increase in the height of teeth). The main line of mammoth development leads from Mammuthus (Elephas) planifrons and M. (Elephas, Archdiskodon) meridionalis, which were warm-latitude forest dwellers of early Pleistocene time, through M. (Elephas, Archdiskodon) trogontherii, a cool steppe dweller of the middle Pleistocene (Gunz-Mindel interglacial into Riss glacial), into M. (Elephas) prlmigenius, a cold steppe and tundra dweller of later Pleistocene times [late Mindel (?) into late Wirm].

The straight-tusked elephants (Loxodonta) were evolving during this same time in more southerly regions of Europe and Africa. Serological tests of the Berezovka mammoth and histological examination of Alaskan mammoth bone indicate close relationship between the woolly mammoths and modern Elephas (Indian elephants). Mammuthus (Elephas) prlmigenius appears to have been a species adapted for extreme cold and tundra conditions, as shown by its smaller size and broad four-toed feet for marshy terrain and by a further decrease in the size of dental plates and the thickness of enamel layers. It seems, furthermore, to represent a dead-end evolutionary development.

The habitat of the woolly mammoth is indicated clearly by its physical appearance and food habits, as determined from the frozen carcasses and

associated fossils. Long hair, thick wool, and a heavy layer of fat definitely indicate a cold climate. Stomach contents reveal an abundance of grasses, sedges, and other boreal meadow and tundra plants, along with a few twigs, cones, and pollen of high-boreal and tundra trees. In general, this floral assemblage is "richer . . . somewhat warmer and probably also moister" than the present flora of the tundra in which frozen mammoth carcasses are now found. Quackenbush found "large trees" associated with fossil mammoth in a now-treeless part of Alaska and also came to the conclusion that the climate was somewhat milder when the mammoths lived. The flora of deposits enclosing frozen mammoth carcasses is similar to that of the stomach contents. Furthermore, the healthy and robust condition of the frozen cadavers indicates that the mammoths fared well on such a diet.

The fauna of which the woolly mammoth formed a part was composed mainly of boreal and arctic steppe- and tundra-dwelling animals, although a few problematical warmer-latitude types appear in some European deposits. The more complex character of this fauna, as compared to the flora, is easily understood in terms of (i) the migratory nature of the large mammals involved and (ii) the fact that most of the faunal assemblages were found in western Europe, which in glacial times was a transition area between glacial and tundra conditions on the one hand and steppe and boreal forest on the other. Soergel strongly emphasizes the effect of seasonal migrations on the faunal assemblages of central Europe, and he points out that woolly mammoths occur only in glacial or transitional (glacial/interglacial) faunas and not in high-interglacial assemblages.

Distribution. Whereas *Mammuthus prlmigenius* was widely distributed throughout most of northern Eurasia and northern North America, frozen remains of woolly mammoths have been found only north of latitude 60°N (mostly north of the Arctic Circle) and distributed around the Arctic Ocean, from the Yenisei River in Siberia to the interior of Alaska. Such a distribution shows the relative abundance of the woolly mammoth in certain parts of the high latitudes and coincides with the present-day content of frozen ground. Even bones of the woolly mammoth are rare in Scandinavia, and they are lacking entirely in most of the Canadian archipelago. Other than two very fragmentary carcasses from Alaska, all of the frozen cadavers have come from northern Siberia. There have been at least 39 discoveries of frozen mammoth remains, with some soft parts preserved, but only four of these were nearly complete: Adam's mammoth from the Lena delta (recovered in 1806), Herz's mammoth from the Berezovka River (1899), Stenbock-Fermor's mammoth from Great Lyakhov Island (1906), and Vollosovich's mammoth from the Sanga-Yurakh River (1907).

The woolly mammoth that has been most intensively studied is that from the Berezovka River. The woolly mammoth most recently discovered, also well studied although by no means a complete carcass, was unearthed on the Mamontova River in the Taimyr Peninsula in 1948. On the other hand, fossil tusks of woolly mammoth are very abundant and have been collected by ivory hunters for centuries. Digby describes a single cache of more than 1000 tusks which he examined in Yakutsk, and Flint mentions some 50,000 tusks from Siberia alone. The obvious conclusion is that the frozen mammoths were members of a populous race located in Siberia (and elsewhere) and not occasional strays who happened to migrate beyond their normal range. And, contrary to some popular accounts, the figures cited above do not support the conclusion that "absolutely countless numbers" of woolly mammoths were frozen and that "many of these animals were perfectly fresh, whole, and undamaged. . . ."

The types of deposits that enclose frozen remains of woolly mammoths help us to reconstruct their habitat, but unfortunately, complete descriptions are not available for some of the early discoveries. "Mammoth-bearing drift" is described by Tolmachoff as usually constituting the locally high portions of the

tundra and lying above sediments of the "last Arctic transgression" [the "Boreal transgression" of current Russian terminology]. Marine fossils have never been discovered in deposits containing frozen mammoths. The Mamontova specimen was found in flood-plain deposits postdating the Boreal transgression, and Digby said that "practically all cold-storage mammoths and woolly rhinos are found on the sides of cliffs sloping down to rivers—a lake in one or two cases." The frozen mammoth found in a bluff facing Eschscholtz Bay, Alaska, was buried in flood-plain deposits, which also included a beaver dam.

Geological Age. Much discussion has centered around the age of frozen mammoths, but several lines of evidence now point toward a solution of this question. To begin with broad categories, we know that woolly mammoths do not exist at the present and that they originated no earlier than the Mindel (second) and probably as late as the Riss (third) glacial stage; therefore, the species occurred in the last half of the Pleistocene epoch.

Flint judged the fauna of the Alaskan frozen muck, which includes woolly mammoth, to be an interglacial fauna, on the basis of some warmer-latitude species which occur there and a series of infinite radiocarbon dates (the oldest being "greater than 30,000 years"). But some finite dates have also come from the Alaskan muck: Bison crassicornis horn sheaths (M-38) were dated 16,000 ± 2,000 years before the present, and skin and flesh of a baby elephant, possibly a woolly mammoth (L-601), were recently dated by the Lamont radiocarbon laboratory at 21,300 - 1300 years. These dates show the complex nature of the muck (silt) deposits and point to the possibility that several, temporally faunas may be mixed together.

The area in northern Siberia in which frozen woolly mammoths are found can be subdivided with respect to the extent of Pleistocene glaciation, as defined by recent Russian work, and thereby can aid in dating some of the carcasses. Almost all of northern Siberia north of the Arctic Circle and west of the Lena River was covered by glacier ice of the Last glaciation, the Zyryansky stage in Russian terminology. East of the Lena only the uplands were glaciated, the arctic coastal plain in that area being left free of ice. In the latter area mammoth cadavers are found outside the area of glaciation, but they overlie marine sediments of the Boreal transgression. In the former area—that is, west of the Lena—mammoths are found above deposits of the Last glaciation which, in turn, overlie sediments of the Boreal transgression.

Russian geologists assign most of the mammoth remains to the Karginsky warm period, an interstadial which followed the maximum extent of the Zyryansky glaciation but preceded the final (Sartansky) expansion of now extinct glaciers of the northern Siberian highlands. It has been suggested that this final expansion was equivalent to the Salpausselka moraines of northern Europe (Valders substage in North America), which formed about 10,500 years ago. Therefore, the mammoths west of the Lena River apparently lived in a relatively warm period prior to the close of the Last glaciation, probably the Allerød or Two Creeks interstadial, of Europe and North America, respectively—a period in which the climate was less warm than at present.

On the other hand, the flora associated with the Berezovka and Mamontova mammoths indicates a climate slightly warmer than the present, and the Lena delta mammoth (Y-633) was dated by radiocarbon as more than 30,000 years old). Both of these facts point to an interglacial age prior to the Last glaciation, a conclusion which is compatible with the occurrence of all mammoths east of the Lena River, including the Lena delta, which appears not to have been glaciated. The Berezovka and Lena-delta mammoths could, therefore, be remnants of the final part of the Last interglacial period.

But the Mamontova mammoth from the Taimyr Peninsula presents a problem: although the associated flora is a warmer-latitude flora than that found

at present, the mammoth lay in an area covered by Zyryansky glaciers and apparently must postdate the maximum of the Last glaciation. The only period since the maximum of the Last glaciation in which the climate was warmer than at present was the postglacial Hypsithermal interval. If Popov is correct in his determination that this mammoth lived at the time of the second terrace above the present floodplain of the Mamontova River, then it probably predates the Hypsithermal interval. It is conceivable but unlikely that two periods of downcutting have occurred there in post-Hypsithermal time. Therefore, an apparent paradox remains—that the climate in northern Siberia was warmer than at present at some period in late glacial time when climates elsewhere on the earth were cooler than at present.

It is also argued that some of the woolly mammoths lived in northern Siberia during the postglacial Hypsithermal interval (7500 to 4000 years ago), but the data on which such a conclusion is based are also compatible with late Last-interglacial time or an interstadial of the Last glaciation. Furthermore, although woolly mammoths are prominent in prehistoric cave art in late Last-glacial time, they are unknown in postglacial deposits in the much-studied areas of Europe and North America. Also, Griffin reports that mammoths were hunted by Siberian Advanced Paleolithic people in the Lake Baikal area as late as 12,000 to 9000 years ago, during the waning stages of the Last glaciation, but that no mammoths of a more recent date are found in these sites.

In summary, Siberian frozen woolly mammoths are found (i) in deposits related in time to the Last glaciation, most of them dating from a major interstadial prior to 10,500 years ago, and (ii) in deposits apparently of late Last-interglacial age (postmaximum Boreal transgression). This time range agrees with that of the distribution of Mammuthus primigenius throughout Europe and North America (including Alaska), where it is found from late (?) Last-interglacial through late Last-glacial times.

Death and Preservation. All the evidence now at hand supports the conclusions of previous workers that no catastrophic event was responsible for the death and preservation of the frozen woolly mammoths. The cadavers are unusual only in that they have been preserved by freezing; the demise of the animals, however, accords with uniformitarian concepts. The ratio of frozen specimens (around 39) to the probable total population (more than 50,000) is of the order of magnitude expected among terrestrial mammals on the basis of chance burial. Furthermore, the occurrence of nearly whole carcasses is extremely rare (only four have been found), in spite of the numerous expeditions for fossil ivory and other exploration in northern Siberia.

There is no direct evidence that any woolly mammoth froze to death. In fact, the healthy, robust condition of the cadavers and their full stomachs argue against death by slow freezing. On the other hand, the large size of their warm-blooded bodies is not compatible with sudden freezing. In addition, all the frozen specimens were rotten and, in most cases, had been somewhat mutilated by predators prior to freezing. This is attested to by many first-hand accounts. Although some of the flesh recovered from the cadavers was "fibrous and marbled with fat" and looked "as fresh as well-frozen beef or horsemeat," only dogs showed any appetite for it; "the stench . . . was unbearable". Histological examination of fat and flesh of the Berezovka mammoth showed "deep penetrating chemical alteration as a result of the very slow decay," and even the frozen ground surrounding a mammoth had the same putrid odor, implying decay before freezing. Furthermore, the stories of a banquet on the flesh of the Berezovka mammoth were "a hundred per cent invention."

Soft parts of other fossils are not unknown in the geologic record, but sudden or catastrophic changes of climate have not been postulated to explain the preservation of these parts. Skin and hair of Pleistocene ground sloths are known

from nonglacial areas. From more remote times we have mummified skin of Mesozoic dinosaurs and muscle fibers of Devonian sharks, still showing individual fibers and cross-striations. Such fossil evidence implies preservation of these soft parts for a considerable period of time—at least as long as was required for lithification of the enclosing sediments.

The only direct evidence of the mode of death indicates that at least some of the frozen mammoths (and frozen woolly rhinoceroses as well) died of asphyxia, either by drowning or by being buried alive by a cave-in or mudflow. As stated above, sudden death is indicated by the robust condition of the animals and their full stomachs. Asphyxiation is indicated by the erection of the penis in the case of the Berezovka mammoth and by the blood vessels of the head of a woolly rhinoceros from the River Vilyui (Siberia), which were still filled with red, coagulated blood.

The specific nature of deposits enclosing the mammoth is not known well enough to be very helpful as an indicator of the mode of death or burial. Most of the remains are associated with river valleys and with fluvial and terrestrial sediments, but whether the mammoths bogged down in marshy places or fell into "riparian gullies" or were mired in and slowly buried by sticky mudflows is not clear. Perhaps all three of these agencies and several others were involved. One point of fact helpful in this problem is the specificity of the frozen animals: in Siberia only mammoths and woolly rhinoceroses have been found frozen and preserved, and the former have been found in much greater numbers than the latter.

So far no other members of the contemporary Eurasian fauna—stag, horse, reindeer, antelope, musk ox, and so on have been found frozen and well preserved. That only the bulky and awkward "giants" of the fauna are so preserved points to some peculiarity of their physique as a contributing factor. The low-slung rhinoceros would have trouble negotiating marshy ground and snow drifts. Similarly, the mammoth, with his stiff-legged mode of locomotion, would have difficulty on such terrain and, moreover, would probably not be able to cross even small gullies. It would be nearly impossible for him to extricate himself if he had fallen into a snow-filled gully or had been mired into boggy ground. A modern elephant is unable to pass over any trench which barely exceeds his maximum stride because of the pillar-like leg structure which is required to support his vast body. Also, the mere weight of the mammoth's body would have been a dangerous attribute if the animal happened to graze too near the edge of a river bluff which had been softened by the summer sun.

The stomach contents of the frozen mammoths indicates that death occurred in the warm season, probably in late summer or early fall, when melting and solifluction would have been at a maximum and, accordingly, locomotion would have been difficult.

The several theories of entombment, which have been alluded to above, generally reflect the theorist's particular experiences or impressions in the mammoth-bearing terrain. Digby was impressed by "countless riparian gullies" which would have been ideal mammoth traps when filled with snow in the winter. Vollosovich was himself trapped in a slowly moving stream of very sticky mud and had to be rescued by his guides. He theorized that an animal so trapped might fall on its side and act as a dam, being slowly buried and suffocated by mud. The Berezovka mammoth is commonly regarded as having fallen as a cliff slumped beneath it; its broken bones attest to such a fall. Presumably it then suffocated as it was buried alive by the caving bluff. Popov believes the Mamontova mammoth perished in a bog while grazing on the floodplain of the ancient Mamontova River. Quackenbush believed that his specimen from Alaska perished on a floodplain and that most of the flesh rotted away before the corpse was naturally buried by floodplain sediments. Another possibility is drowning

by breaking through river ice. All of these theories are credible and can be accepted as possibilities. There appears to be no need to assume to occurrence of catastrophe.

Conclusion. Although some problems concerning the frozen fauna of Siberia and Alaska remain to be solved, recent field work and new techniques have contributed much to our understanding since Tolmachoff's summary account in 1929. Frozen woolly mammoths have now been found in northern and northeastern Siberia and Alaska in deposits attributed to Last interglacial and Last glacial times. They are unknown in postglacial deposits. Only four of the 39 known frozen carcasses are by any means complete, and all of the cadavers were rotten and somewhat mutilated prior to being frozen. More than 50,000 mammoths lived in Siberia during late Pleistocene time.

The woolly mammoths lived in a tundra region similar to that in which they are found today, but the climate was slightly warmer and perhaps moister. They were apparently well adapted to the cold climate; their long hair, warm underwool, and thick layer of subcutaneous fat protected them against the cold air, and their broad, four-toed feet and relatively small size (as compared to that of their fossil European relatives) were advantageous in marshy pastures. The frozen mammoths were healthy and robust when they died.

The well-preserved specimens, with food in their stomachs and between their teeth, must have died suddenly probably from asphyxia resulting from drowning in a lake or bog or from being buried alive by a mudflow or cavein of a river bank. Since only the heavy-footed giants of the fauna—the mammoths and woolly rhinoceroses—have been found in a frozen state, it is very unlikely that a catastrophic coagulation occurred in Siberia. On the contrary, the frozen giants are indicative of a normal and expected (uniformitarian) circumstance of life on the tundra.

EBM-007 RIDDLE OF THE FROZEN GIANTS

Sanderson, Ivan T.; Saturday Evening Post, 232:39+, January 16, 1960.

Most of Sanderson's article consists of surmises about how mammoths (and other animals) were quick-frozen in the arctic muck. Sourcebook policy aims at presenting data rather than theory. Therefore, only Sanderson's intriguing catastrophism-oriented summaries of the basic facts are reproduced below.

About one seventh of the entire land surface of our earth, stretching in a great swath round the Arctic Ocean, is permanently frozen. The surface of some of this territory is bare rock, but the greater part of it is covered with a layer, varying in thickness from a few feet to more than 1000 feet, of stuff we call muck. This is composed of an assortment of different substances, all bound together with frozen water, which becomes and acts as a rock. While its actual composition varies considerably from place to place, it is usually for the most part composed of fine sand or coarse silt, but it also includes a high proportion of earth or loam, and often also masses of bones or even whole animals in various stages of preservation or decomposition. So much of the last is there on occasion that even strong men find it almost impossible to stand the stench when it is melting. This muck is spread all across northern Asia and is exceptionally widespread in Northern Siberia. It appears again in Alaska, and lies right across the top of Canada almost to Hudson Bay.

The list of animals that have been thawed out of this mess would cover several pages. It includes the famous woolly mammoths and woolly rhinoceroses, horses like those still existing wild in Asia, giant oxen and a kind of huge tiger. In Alaska it also includes giant bison, wolves and beavers, and an apparently quite ordinary lion as well as many other animals now extinct and some which are still in existence, like the musk ox and the ground squirrel. The presence of the extinct species provides us with a fine set of riddles, and of those that are not extinct, with another set; and the absence of still others, like man, for instance, with a third set. The greatest riddle, however, is when, why and how did all these assorted creatures, and in such absolutely countless numbers, get killed, mashed up and frozen into this horrific indecency?

These animal remains were not in deltas, swamps or estuaries, but were scattered all over the country,- Almost without exception, they were stuck in the highest levels of the curious, flat, low plateaus that occur all over the tundra between the river valleys. It was also pointed out that the whole of Northern Asia, Alaska and Western Canada could never have been one vast delta, nor could their rivers have wandered about all over this higher land, depositing muck uphill. But last, and worst of all, many of these animals were perfectly fresh, whole and undamaged, and still either standing or at least kneeling upright.

Sanderson notes here that these facts forced the abandonment of the theory that water was the agency that killed these animals.

The flesh of many of the animals found in the muck must have been very rapidly and deeply frozen, for its cells were not burst and, although one mammoth has been found by the radiocarbon dating method to be just over 10,000 years old, the flesh of these animals was remarkably fresh and some was devoured by the explorers' sledge dogs.

After hypothesizing that the Siberian mammoths may have been quick-frozen by a sudden drop of temperature, Sanderson speculates that catastrophism (winds, tidal waves, etc.) may have also decimated arctic regions.

This is exactly the state of affairs that we find in Alaska, where the mammoths and other animals, with one or two significant exceptions, were all literally torn to pieces while still fresh. Young and old alike were cast about, mangled and then frozen. There are also, however, other areas where the animals are mangled, but had time to decompose before being frozen; and still others where they decomposed down to bones and were then either frozen or not. Beyond these again, there are similar vast masses of animals, including whole families or herds, all piled together into gulleys and riverbeds and other holes, but where only bones remain.

EBM-008 THE GLACIATED GRAVE OF THE MAMMOTH IN SIBERIA

Anonymous; Current Opinion, 61:330, November 1916.

The whole of northeast Siberia is one vast graveyard filled with the bones of animals that have perished within comparatively recent times. Little does the

traveler think, says the physical geographer, Doctor D. Gath Whitley, that the ground under him only a few feet below his sled is packed full of the bones of enormous animals which have perished in some mysterious manner since man appeared upon the earth.

The whole of northern Siberia, from the Ural Mountains to Bering Strait, is one vast graveyard filled with animal remains. The bones, teeth and skulls are those of elephants, rhinoceroses, buffaloes and musk-oxen. These bones occur everywhere. They are found on the banks of the rivers, in the plains, on rising ground and in frozen cliffs. On the shores of the Arctic Ocean there are sloping banks of ice. These are split and furrowed in all directions with deep chasms. As the traveler looks down into their dark depths from above, he sees that the lower portions of these icy chasms are filled with tusks, bones and skulls in countless abundance. We quote from Chambers's:

"In other places on the northern coast of Siberia fronting the Arctic Ocean the low cliffs which rise above the beach and are formed of earth and clay are full of the bones of elephants and rhinoceroses. In the brief summer, which hardly lasts for six weeks, portions of these earthy cliffs thaw and fall on the beach below. Then it is that the traveler who walks along the shore witnesses an astonishing spectacle. Not only does he observe icebergs stranded on the beach but he also sees the tusks, bones, and teeth of elephants (the mammoth) lying on the shore and whitening the beach for long distances! If he leaves the Arctic Ocean behind and journeys inland, the same sights constantly meet his astonished gaze. He comes, it may be, to a plain where for perhaps half a mile the whole ground seems to be formed of masses of tusks, teeth, and bones of elephants and rhinoceroses welded together in one confused mass in the frozen soil. These mighty beasts must have been destroyed in herds, but how they perished no one knows.

"Still more amazing is the fact that the islands in the Arctic Ocean north of Siberia are equally full of the tusks and bones of elephants and rhinoceroses; and on the shores of these islands in the Polar Sea the tusks of elephants can be seen sticking up like trunks of trees in the frozen sand!

"Stranger still, actually the very bodies of these great elephants, with flesh, fur and hair perfect, are seen standing upright in the frozen cliffs.

"When the cliffs thaw, the bodies of these great elephants fall to the ground, and are so perfect, after being entombed for thousands of years, that the wolves eat the flesh!"

Descriptions of the Siberian "boneyards" inevitably invoke claims of catastrophism, such as a sudden shift of the earth's pole of rotation.

EBM-009 PERENNIALY FROZEN GROUND IN ALASKA: ITS ORIGIN AND HISTORY

Taber, Stephen; Geological Society of America, Bulletin, 54:1433-1548, 1943.

Much that has been written about the arctic muck is sensational in tone. Taber offers some sober, matter-of-fact descriptions of his findings.

Most of the buried wood is white spruce (Picea glauca, formerly called P. canadensis), but in places willow is more abundant, and birch, alder, aspen, and **Cottonwood** are found. Spruce cones, in part unopened, spherical enlarge-

ments on the trunks of trees due to injury when young, bracket fungi, leaves, and several kinds of seed are present. Spruce and willow are commonly well preserved, but birch is apt to be badly decayed, and ordinarily only the flattened bark remains. Most of the spruce was slightly altered and thoroughly water soaked before freezing, for it is badly splintered by frost with separation along the annual layers. The condition of the wood indicates long burial in silt saturated with water. These facts tend to support the conclusion that the ground was not perennially frozen while the silts were accumulating.

The roots and stumps of trees are commonly found in place, but the tops have been broken off and carried away. Four successive forest horizons, marked by tree roots in place, were exposed in a drainage ditch in Goldstream Valley about 2 miles below Fox; and F. M. Fenton, of the Fairbanks Exploration Company, has observed five such layers, one above the other. The trees were probably killed by silt deposition which prevented access of air to the lower part of their trunks. Their tops were then broken off by storm and flood and carried away.

Many stumps and roots of both fossil and recent spruce were exposed during the thawing and removal of the silt, thus facilitating comparison. The roots of modern spruce, growing where perennial frost is close to the surface, spread out radially at very shallow depths, and the annual rings are thicker on the upper half of roots and thinner on the lower half. The roots of the fossil trees extended deeper, thus indicating growth on ground where perennial frost was either absent or deeper than at present. None of the trees showed additional roots like those sent out by spruce growing on frozen ground when the older roots cease to function because of the accumulation of moss and peat with the consequent rise in frost level, and none showed evidence of reproduction by upward growth of root tips, such as Harshberger found where trees encroach on the tundra.

The distribution of fossil trees also indicates a somewhat milder climate during the silt accumulation than that now prevailing. Today Seward Peninsula is treeless, except for a thin growth of small spruce in some of the valleys in the extreme eastern part, but large spruce logs are found in the silts at many places on the peninsula and even farther north. It has been suggested that the logs floated from distant sources during a period of high sea level, but the silts unquestionably accumulated under subaerial conditions for they contain numerous bones of land mammals, small twigs, spruce cones, and even tree stumps in place. In the silts of Candle Creek and its tributaries, birch and willow logs 6 to 10 inches in diameter, as well as spruce, occurred with the bones of mammoth, bison, and other Pleistocene animals. On Quartz Creek bones of mammoth and horse were found with the trunks of large spruce trees, one of which is said to be 5 feet in diameter and 80 feet long. Moffit and others have also reported large spruce logs in the valley slits of Seward Peninsula. At Elephant Point, Quackenbush found a tree stump in place. Spruce logs, including one with roots attached, were found along the Ikpiuk in Lat. 70°N at an elevation of more than 200 feet although spruce is not known to live north of the Brooks Range.

Pleistocene deposits exposed in cut banks of the Mackenzie River delta contain tree stumps in place, and similar deposits exposed in cliffs on Herschel Island contain twigs. The tree stumps are all upright, in place and most of them over 18 inches in diameter, although none of the trees in the delta today exceeds 9 inches. Some of the fossil trees belong to species different from any in the region today. The wood is splintered and "breaks off in circular slabs about one-quarter inch thick", as in the Fairbanks district, where buried spruce was altered and water-soaked before freezing. According to Porsild, well-preserved roots and stumps of a former spruce forest are found in situ and covered with many feet of peat, on Richards Island, 60 to 70 miles north of the present tree limit. In peat deposits, thought to be older, on the east branch of the Mackenzie delta, he found larch (tamarack) cones more than 50 miles north of the present

range of this tree.

In Lat. 74°N. on Great Lyakhov Island in the New Siberian Islands group, Toll found specimens of alder (Alnus fruticosa) "consisting of the whole trunk and roots to a length of 15 to 20 feet," with bark intact, although its northern limit today is 4° to the south. Willow and birch, bearing well-preserved leaves, were also found, (pp. 1482-1484)

Vertebrate remains in creek-valley silts.—Fossil bones of typical Pleistocene mammals are abundant and widely distributed in the valley silts of the non-glaciated area. They have been found from the small headwater streams to the coasts. Even in mantle deposits a few bison bones were exposed in a new road cut on the southwest side of Dome Creek at an elevation of about 265 feet above the creek and 950 feet above sea level. The mammals have been listed by Richardson, Dall and Harris, Gilmore, Osborn, Frick, Wilkerson, and others. Unfortunately, little or no attempt has been made to determine the exact horizon in the gravels and silts from which the different fossils came.

In valley deposits, the remains of bison, chiefly the giant B. crassicornis, were most abundant, with those of horse or mammoth next. The mammoth has been reported from more localities in Alaska than any other mammal, probably because of the commercial value of the tusks, the ease of identification, and the great popular interest in these animals.

The extinct species include the dire wolf (Aenocyon or Canis dirus claskensis), the short-faced bear (Arctotherium yukonensis), three bison B. crassicornis, B. alleni, and B. occidentalis, the musk-ox (Ovibos maximus or yukensis), two musk-ox-like animals (Symbos tyrelli and Bootherium sargenti), the camel (Camelops), the great American lion (Felis atrox alaskensis), the horse (Equus alaskae), the hairy mammoth (Mammuthus primigenius), the mastodon (Mastodon americanus), and, doubtfully, the Columbian mammoth (Parelephos columbi).

The presence of caribou (Rangifer), moose (Alce), wapiti (Cervus), and bear (Ursus), all late immigrants that have persisted with little or no modification, indicates a land connection with Asia during or shortly before silt and gravel deposition. With reference to the caribou, moose, and wapiti, Scott states that "none of these mammals has been found in America in deposits older than Pleistocene, nor anything that could be ancestral to them." The Siberian mammoth (M. primigenius) is another Pleistocene immigrant.

A considerable extension of present land areas, during at least part of Pleistocene time, is indicated by the remains of the Siberian mammoth on many northern islands as well as on the two continents. The remains of mammoth and other extinct mammals are abundant on the New Siberian Islands, 150 miles north of the Asiatic mainland, and on the Bear Islands farther east. According to Mecking, they are also found on Bennett Island, northeast of the New Siberian Islands, though De Long does not mention this. Mammoth tusks are reported on Wrangel Island, north of Siberia, by Gilder, and on Banks Island, north of Mackenzie Territory, by Kindle. All these islands are on the barely submerged continental shelf, which between Alaska and the Taimyr Peninsula is about 500 miles wide. Mammoth remains have also been reported on King Island, 40 miles southwest of Seward Peninsula, on the St. George and St. Paul islands in the Pribilof group, and on the island of Unalaska in the Aleutian group but these have been questioned.

All the species listed above could live in a cold climate, but the musk-ox and his close relatives—Symbos Tyrelli, Bootherium sargenti, and Ovibos yukensis—are typical of the Arctic tundra. The natural habitat of the bison, horse, and lion is the grassy plains of a somewhat milder climate. Possibly the musk-ox and caribou reached central Alaska a little later than the horse, bison, and lion,

and after the climate had become colder but direct evidence is lacking.

The northern range of the American beaver coincides with the limits of forest growth, but beaver-cut wood and even beaver dams are found in frozen silts beyond the present forest line. A beaver dam at Elephant Point has been described by Hooper, Nelson, and Quackenbush. Moffitt found a beaver dam in silts on Old Glory Creek near Deering. Brooks reported beaver-gnawed wood in ice in the Kougarok region, and the writer found it in silts on Candle Creek.

Mammoth remains have been found along the north coast of Alaska and on the Banks Island as far north as Lat. 72°. On the Taimyr Peninsula and in the New Siberian Islands, as far north as Lat. 77°, they are very abundant. Pfizenmayer states that in the New Siberian Islands collectors have "found inexhaustible supplies of mammoth bones and tusks as well as bones and horns of rhinoceros and other diluvial mammals"; and Dr. Bunge, during expeditions in the summers of 1882-1884, "gathered almost two thousand five hundred first-class mammoth tusks on the New Siberian islands of Lyakhov, Kotelnii and Fadeyev." although many collectors had previously obtained ivory from the islands since their discovery in 1770 by Lyakhov.

The mammoth was well protected against cold by its undercoat of wool and overcoat of long hair, but it was not adapted to feed on lichens and other tundra vegetation in winter as are the caribou and musk-ox. Scott states that its food in summer time "consisted almost entirely of grasses, and, in winter, of coniferous twigs and leaves." Although the mammoth probably fed also on other vegetation, it could not have found sufficient food in winter in Lat. 77°N. if the climate was as severe as it is today, (pp. 1486-1488)

Fossil bones are astonishingly abundant in the frozen ground of Alaska, but articulated bones are scarce, and complete skeletons, except for rodents that died in their burrows, are almost unknown. Of several tons of bones of the larger mammals seen in 1935, four bison vertebrae were the only ones found in a position indicating original articulation. The dispersal of the bones is as striking as their abundance and indicates general destruction of soft parts prior to burial. However, occasional articulated bones indicate primary burials.

In the Fairbanks district, even the hard parts of animals commonly show evidence of weathering; some of the bones and tusks are coated with vivianite; horn-cores are common, but horn-sheaths are rare; and mammoth tusks are, for the most part, badly discolored and exfoliated supplying practically no commercial ivory. The bones are generally unbroken and are not abraded or waterworn. On Seward Peninsula fossil ivory is found and used by the Eskimos, though most of it is brown rather than white. Near the north coast of Alaska more of the ivory is of good quality, but the great bulk of the world's supply of mammoth ivory comes from more northerly latitudes in Siberia and on Arctic islands.

In general, the proportion of well-preserved to poorly preserved hard parts tends to increase northward. Soft parts were preserved only under exceptional conditions of prompt burial after death, usually in floodplain or delta deposits as a result of floods, but occasionally under mudflows or in bogs and ponds.

The decomposition of bones and tusks with the formation of vivianite is partly a biochemical process, and the mineral is characteristic of weathering in a wet, if not a swampy, environment.

Numerous references are found, especially in semi-popular literature to "bone yards," "bone pits," "bone beds," "elephant graveyards," and natural "traps," but the writer has seen no evidence of such features. The bones are, naturally, more abundant in some localities than in others but they have been

found In practically every valley where placer mining has been carried on.

The abundance of fossil bones in the nonglaciaded area has been attributed to northward crowding of Pleistocene animals by an expanding ice cap, but the decrease in the habitable area took place gradually, and at any given time the number of animals per unit area was determined by the food supply and similar environmental factors. It has not been proved that the deposition of the silt coincided with the period of maximum ice expansion, but, even if it did, there is no reason to assume that the density of the animal population would have been greater north of the ice cap than south of it, where the climate was milder. The abundance of both plant and animal fossils in the Alaska silts, as compared with their occurrence in Pleistocene deposits south of the glaciaded area, must be attributed to better preservation in the colder climate, (pp. 1489-1490)

EBM-010 MUCH ABOUT MUCK

Anonymous; Pursuit, 2:68-69, October 1969.

In a fine report on a highly informative talk given by a Mr. E. M. Benson, Vice-President of the North American Producing Division of the Atlantic Richfield Oil Company, to the Long Beach Petroleum Club of California on the new oilfield in northern Alaska, there appeared a rather noteworthy quote. This read: "Drilling down through the 1000-foot thick frozen earth can produce some surprises. One of our wells brought up an 18-inch long chunk of tree trunk from almost 1,000 feet below the surface. It wasn't petrified—just frozen", the oil company executive said. The reason this statement is noteworthy is not because the reporter seems to have been impressed but rather that a man of Mr. Benson's experience—and he started as a worker in the fields—should use the word "surprise" in this case.

We are going to hear a lot about this frozen earth or 'muck' from now on because of this vast oil strike on the Arctic shores of the Alaskan peninsula. It is indeed full of surprises but a tree trunk in it, and even at a depth of a thousand feet, is not at all surprising. What surprise there was on this occasion was probably due to the fact that it came to light in an area devoid of trees today and hundreds of miles from any forest growth. The nature of muck is not generally understood, and the theories on its origin are even less widely known.

Frozen soil, as diametrically opposed to ice on the one hand and rock on the other, constitutes one of the greatest mysteries on our earth's surface. What is more it covers no less than one seventh of the land surface of the earth, and all of it encircles the Arctic Ocean and lies within the Arctic circle at what we consider the top side of our planet. Actually, it is a form of 'rock', despite its very mixed composition, at least to the extent that a tillite or puddingstone may be. The reason for stating this is that the material that binds it is water, and water in its solid form as ice is also technically a rock and behaves as such. When this frozen soil melts it results in an appalling and often stinking sort of soup composed of goo with silt, sand, pebbles, and boulders, often with masses of preserved, semi-decayed, or fully decayed vegetable and animal matter. This is what is called "Muck".

A world map of the distribution of this frozen soil and muck reveals several very interesting things, the most outstanding aspect being that it lies on low, level plains or tablelands. Unless it was caused by some cosmic forces that we have not yet detected, it would appear to be a subaerial deposit derived from massive erosion of higher grounds and with steeper slopes. However, its depth in some places, and over enormous areas, has always caused even the most open-minded geologists to boggle. The Russians, who own the major land areas covered by this substance, have conducted prolonged studies on it for half a century and have in some places drilled down to over 4000 feet but still without reaching solid rock. The conundrum is, of course, how do you get that thickness of what is manifestly surface-derived material if it is the result of mere run-off? To this there would appear to be but one answer.

First, the lands now blanketed with this material must at one time have been much higher above sealevel, so that stuff could be deposited upon them, rather than running on beyond and out into the sea. Alternatively, the sea level would have to have been much below that of today; but in this case are we asked to suppose that universal sealevel was not too long ago, geologically speaking, more than 4000 feet lower? If neither of these situations pertained when the first, and lowest layers of this muck were laid down, just what were the conditions, since no such strata could be laid down even under shallow, tranquil coastal seas? To suggest that the uplands from which this stuff came were much once higher and had a steeper run-off is begging the question, and doesn't help at all. Yet, there is the bloody muck lying all over the lot and to enormous depths. It has to be accounted for.

Let us next turn back to Mr. Benson's remark. This was to the effect that finding a section of a fair-sized tree trunk a thousand feet down in this frozen muck was a 'surprise'. It may indeed be to the average person who has not had cause to investigate or read about this incredible natural phenomenon, but it comes as no surprise at all to geologists who have specialized in the surface constitution of the Arctic regions. A mere section of tree trunk is a mild relief compared to some of the things that the muck has yielded. In the New Siberian Islands for instance, whole trees have turned up; and trees of the family that includes the plums; and with their leaves and fruits. No such hardwood trees grow today anywhere within two thousand miles of those islands. Therefore the climate must have been very much different when they got buried; and, please note, they could not have been buried in frozen muck which is rock-hard, nor could they have retained their foliage if they were washed far north by currents from warmer climes. They must have grown thereabouts, and the climate must have been not only warm enough but have had a long enough growing period of summer sunlight for them to have leafed and fruited.

Ergo, either what is now the Arctic was at the time as warm as Oregon, or the land that now lies therein was at that time elsewhere. Geophysicists don't go for an overall warming of this planet to allow such growth at 72 degrees north; otherwise everything in the tropics would have boiled! Thus, we are left with the notion that either the whole earth's crust has shifted, or bits of it have drifted about. But then comes another problem—the Time Factor.

Along with the plum trees, and other non-arctic vegetation there are found associated animal remains of many kinds. One of these is the famous mammoth. Now, everybody has somehow got the totally erroneous idea that these great hairy beasts are found in ice. Not one has ever been found in ice: they are all in this frozen earth or muck. Then, just because of their layer of fat and their covering of long hair everybody likewise thinks that they were arctic types. A moment's consideration will disclose just how ridiculous an idea this is. A large elephantine needs some half a ton minimum of fresh green food a day to maintain itself, and there were apparently (at least according to the number of

their bones and bodies that have been found in the muck) hundreds of thousands of them up till only a few thousand years ago. For a minimum of eight months out of the year there is nothing for such large animals to eat north of the tree line in the Arctic, though some Barren Ground Caribou and a few Muskox get along by scratching through the shallow snow to get at tundra moss and lichens. Therefore these elephants must have migrated far south for the winter or the climate must have been much milder than it is today, or the lands they lived in were elsewhere.

But not even this pinpoints the reason for the muck or explains just how all the junk that is found in it, even down to thousands of feet, got there. Mr. Benson's tree trunk may not have been a surprise but it is still a mystery in one way. And we should contemplate the many aspects of this mystery in order to be ready for the many more enigmas that we are going to be told about as our technicians slice into the far north.

EBM-011 ON THE OCCURRENCE OF MAMMOTH AND MASTADON REMAINS AROUND HUDSON BAY

Bell, Robert; Geological Society of America, Bulletin, 9:369-390, 1898.

The frozen mammoth carcasses in the Arctic were controversial even in the Nineteenth Century—long before Sanderson, Price, Velikovsky, and other modern catastrophists. Here is an early condemnation of anti-uniformitarians.

Extinction of the Mammoth in Siberia. The mammoth in northern Siberia probably passed the winters within the forest-line, where he would find shelter from the chilling winds and where he might live well, browsing on the small branchy spruce, larch, birch, etcetera. With the advent of spring he would begin his northward march, taking advantage of the long daylight, and he would spend part of the summer and the autumn roving about the shore of the Arctic sea, enjoying the cool weather and finding abundant sustenance on the small trees and the alder, willow, and birch brushwood. Then, with the beginning of the severe weather, he would turn his footsteps toward his winter quarters and move south as the season advanced. The periods of their annual migrations having become settled, it would be difficult or impossible to overcome the inertia of long-fixed habit, and they would be obliged to endure the increasing severity of the climate on the borders of the Arctic sea. In the meantime their numbers would be greatly diminished from causes to be mentioned further on. At length, those which journeyed as far as the sea coast might be reduced to the single herd which migrated to the mouth of the Lena, where the climate of autumn would be the best on the coast, owing to the large quantity of warm water from the south which accumulates off the mouth of this great river.

At this stage, if an unusually early and severe season were to set in, accompanied by great snow-storms, before the herd had started for the south, the result might be disastrous to the remaining mammoths. The now stunted brush would be covered by the deep snow, on which perhaps a strong crust had formed, thus preventing the animals from obtaining any food, while the almost continuous darkness of the early winter would also operate against them. The same conditions would make it difficult or impossible for them to travel. Other individuals or herds which did not migrate so far north may have perished

from a similar cause in various parts of the region. We know how completely helpless the deer of any species become in our northern woods when caught in deep snow with a crust upon it.

Under circumstances like these the last of the mammoths would soon perish, since creatures of their organization, living upon such slightly nutritious food, must have it continuously and in large quantities. That such a process of starvation is not imaginary, I may mention the fact that the reindeer sometimes perish over large areas in our northern barrenlands from this cause. Their lives depend upon a continuous supply of the reindeer-lichen, which they obtain by removing the snow or by finding the plant where the ground has been left bare by drifting. A striking instance of this occurred many years ago on Akpatok island, in Ungava bay. This large island had always swarmed with reindeer, but one winter, when the snow was deeper than usual, rain fell upon it (an almost unprecedented occurrence) and formed a heavy and permanent crust over both the bare ground and the snow, thus preventing the deer from obtaining their food. The consequence was that the whole number perished, and the island has never been restocked. If this former great herd had comprised the whole species then living, the reindeer would now be extinct.

Preservation of the Flesh of Mammoths in Siberia. The preservation till the present day of the flesh of some of the mammoths which perished in the region about the mouth of the Lena river and elsewhere proves that the carcasses must have become frozen immediately after death, and this circumstance may be accounted for in the following way: If the last of these creatures succumbed in the manner supposed, there may have been at that time a series of unusually cold years, as sometimes happens in high latitudes, and this, together with the increasing severity of the climate in general ever since, would account for the preservation of some of their carcasses in the snow and ice which have persisted in that region till the present time.

The occurrence of large numbers of the remains of mammoths in the alluvial deposits about the mouth of the Lena and other rivers may be explained by the supposition that the animals had broken through the too thin ice in attempting to cross the streams upon it on their southward migration in the autumn, and that their bodies had subsequently floated down to the still water. Indeed, it is highly probable that whole herds of these animals lost their lives in this manner. While the bison was abundant in our northwest territories it was a matter of common occurrence for large numbers of them to be drowned when attempting to cross the streams in compact droves before the ice was strong enough to bear the strain. The great abundance of bison bones in some of the fluvial deposits in this region is easily accounted for in this way.

The mammoths, owing to their great weight, would be still more liable to such an accident. Professor Richard Lydekker, in "The Royal Natural History," lately published, speaking of the trade in ivory from Siberia, says that within a recent period, covering twenty years, 20,000 mammoths must have been discovered in that region.

Improbable Theories. The supposition that the mammoth of northern Siberia were frozen where we find them by a sudden change from a warm to a very cold climate, and which has remained permanently so, is as untenable as the other theory, which supposes the bones and tusks found there to be those of mammoths which were drowned in great numbers and at the same time within a limited area by a sudden cataclysm. If it were possible (which it is not) that such an abrupt change of climate could happen, it would require to be general around a great part of the globe, and there is no evidence that such a thing occurred at any time in the history of the earth. Again, to invoke the agency of sudden cataclysms to account for geological phenomena is an exploded notion which does not require discussion, (pp. 377-380)

On occasion, more frequently a century ago than now, reports have cropped up of animals entombed in solid rock or found in other seemingly impossible situations. Sometimes the animals are even revived but they usually succumb shortly. It is easy to dismiss these purported discoveries as hoaxes because they seem to controvert many of our cherished ideas in geology and biology. More of these curious tales will appear in future volumes in this series. Meanwhile, here are a few documented cases to test your credulence.

EBR-001 A TOAD IN THE SOLID ROCK

Arnold, A. W.; Scientific American, 29:212, October 4, 1873.

The other day Mr. Moses Gains of this place, while digging into a bank, found a toad embedded in the hard pan. He came to a stone some 2 feet square; and after digging this out, a man who was with him observed something black: taking his pickaxe, he carefully dug it out, and it proved to be a toad. It was some six inches below the surface of the stone, and its place of concealment was as smooth as if it had been made of putty. The toad was about 3 inches long and very plump and fat. Its eyes were about the size of a 3 cent silver piece, being much larger than those of toads of the same size such as we see every day. They tried to make him hop or jump by touching with a stick, but he paid no attention to them.

How came this toad embedded, 5 feet below the surface under a stone, in that hard pan? What did he subsist on? Will such toads live on being brought to the light? Is there any air in the ground, on which a toad could live, and how long must we suppose that he had been there? (New Hartford, CT)

EBR-002 A MUMMIFIED FROG

Shufeldt, R. W. ; Science, 8:279-280, September 24, 1886.

Not long ago Mr. James Stevenson of the U. S. geological survey visited me for a day or two at Fort Wingate, and while here invited my attention to an interesting specimen that had fallen into his possession during a recent trip he had made in the coal regions of northern Pennsylvania. The specimen consists of a mummified frog taken from the coalmine of McLean county, Penn., and the following account of it is from a local newspaper loaned me by Mr. Stevenson for the present purpose. I quote the short notice in full; and the writer of it says, "One of the most curious finds unearthed lately in this region, and what may yet prove a valuable fact in the study of science and history, was singularly found by Eddie Marsh, the fourteen-year-old son of Mr. D. B. Marsh, a book-keeper for Stevenson Brothers, hardware dealers. Eddie, becoming impatient at the fire in the stove, which was not burning vigorously, took the poker and began punching it. A large lump of coal lay smouldering, and he determined to break it; and, after punching at it for a moment, the lump burst open as if by explosion, and a number of pieces flew out of the stove. One piece he caught, and he was in the act of casting it back into the stove, when its lightness attracted his attention. On viewing it, he saw that it was nothing less than a perfectly formed frog. On last evening a large number of persons viewed the little curiosity. It had been embedded in the centre of the large lump of coal, and its bed was plainly discernible when the lump was laid open. The lump of coal came from the third vein of coal in the McLean county coal-shaft, which is 541 feet under ground. The curiosity apparently was not petri-

fled. Apparently It had been mummified instead. It was shrivelled until it is about half the size of a full-grown frog, and it is light and soft. Its shape is perfect, and the warty protuberances of the skin are very plain. Its limbs are regular and properly shaped, including the finger-like toe of its feet, and its eyes and mouth are natural. There can be no doubt of its being a mummified frog, and now various and tough questions arise regarding it: How did it get that far under ground? How did it become embedded in that chunk of coal, which probably had been blasted from the center of a thick vein: How many thousands of years had it been buried? and various other queries, which we will leave for the scientist to unravel and explain. "



Mr. Stevenson tells me that he is personally acquainted with all the parties concerned in the discovery of this specimen, and has carefully examined the piece of coal whence the mummy was taken, and says, further, that it came from the vault, and not from either the sides or the floor of the mine.

He has done me the honor to turn the specimen over to me for diagnosis, as well as to take such steps as I saw fit to ascertain if there be any similar cases on record, and, finally, how geologists or paleontologists explain such finds as this. The specimen is now before me, and I at once recognized it as a species of *Hyla*, though I am unable to say which one. It apparently agrees in all its external characters with a specimen I have of *Hyla versicolor*, kindly diagnosed for me by Professor Cope last summer, though it is rather smaller. As will be seen from the life-size figure I have made of it, which illustrates this letter, it is in nearly a natural position; its feet, however, are somewhat drawn up under it. I have figured it as viewed directly from above. It is completely mummified, and in a wonderfully perfect state of preservation, being of a dark, snuff-brown color, somewhat shrunken, and, in short, reduced to a condition, that, if properly excluded from the air, would keep for an indefinite length of time. I am aware that these tree-frogs very often climb into some of the most unheard-of places; but it struck me that it would be interesting to have some one tell us if they ever heard of a *Hyla* finding its way to the vault of a coal-mine 541 feet under ground, and climbing Into the solid coal-bed after getting there.

EBR-003 A TOAD IN SANDSTONE

Anonymous; American Journal of Science, 1:29-353, 1836.

A toad in sandstone was discovered at Park Gardens, Coventry, during the making of excavations now in progress there; "the animal was reinstated in his narrow bed by the engineer, but it survived only four days. "

When the remains of marine animals are discovered hundreds of feet above present sealevel and (sometimes) miles inland, a likely inference is that either the sea had receded or the land had risen in relatively recent times. Another possibility is that catastrophic floods of seawater might have carried these animals to their anomalous locations. Thus, such biological indicators may tell us something about the Earth's recent history.

EBS-001 RECENT CHANGES IN CIRCUMPOLAR LANDS

Howorth, Henry H.; Nature, 5:162-163, December 28, 1871.

That changes in sealevel have occurred in circumpolar lands is not controversial. How much and when are at issue now. Howorth, a proponent of the Deluge, infers that the changes are large and recent.

The question of the upheaval and subsidence of different areas of the earth's surface, as it is going on at the present moment, is of very great importance in geology, and yet few subjects have been more neglected. A few facts have been here and there collected; but even the best authorities treat the matter in a jejune fashion. According to them the areas of upheaval and subsidence are scattered over the earth's surface in an irregular manner, without any definite law or rule. I believe that with very slight local exceptions there is a very distinct law which governs the subject.

Putting aside altogether the southern hemisphere for the present, I wish to prove that the area of upheaval is confined to the land bordering the Polar Sea, and to the Polar Sea itself; that it is perfectly continuous all round the earth, and that it is greatest near the Pole, and gradually diminishes until it disappears about the 57th parallel, leading to the conclusion that the focus of upheaval is the Pole itself.

Of course, my observations are entirely confined to what is taking place now, and are not to be confused with the facts of any other period, historical or geological.

Commencing with Scandinavia, we have the remarkable testimony of Pliny, Mela, Solinus, and others, to the fact that Scandinavia was considered by the Roman geographers, whose authorities were bold and expert seamen, to be an archipelago. Ptolemy speaks of the Scandian Islands. The very name Scandinavia is evidence that those who used it looked upon it as an island. This implies that a great deal of dry land must then have been under water. In 1834 Sir Charles Lyell wrote his Bakerian lecture, in which he brought forward overwhelming evidence to prove that Scandinavia was then being gradually upheaved. Celsius, who wrote in the 17th century, had affirmed it, and calculated the rise at forty inches in a century. In 1807 Von Buch wrote that all the country from Frederickstadt, in Sweden, to Abo, in Finland, and perhaps as far as St. Petersburg, was slowly rising. Other authorities concurred, and lastly Sir Charles Lyell, who had approached the subject as a sceptic, was fully convinced after an exploration of the ground. At Stockholm he found striking proofs of change since the Baltic acquired its present tenants, Testacea found there seventy feet above the sea level being identical with those found in the adjacent sea. At Soderleige, a little farther south, and in a bed ninety feet above the sea level, besides the shells were found several buried vessels, made of wood, and joined with wooden pegs. In another place an iron anchor and nails were found. At Upsala brackish water plants were found in meadows where there are no salt springs; a proof that the sea had only recently retired. At Oregrund, forty miles

to the north, the land had risen five inches and a half since 1820, and at Gefle were low pastures, where the inhabitants' fathers remembered boats and even ships floating. Experienced pilots in the Gulf of Bothnia estimated the fall of the waters at two feet in thirty years. Since Sir Charles Lyell's lecture both the Russians and the Swedes have made experiments all proving the same fact.

To the east of Scandinavia we have Finland, exhibiting all the characteristics of a recently-emerged land. It is a mere congeries of lakes and swamps, separated by moss and sand. The level of the lakes is constantly falling. In 1818 Lake Sovando was suddenly lowered; its waters escaped into Lake Ladoga and much of its bottom was exposed. Similar traditions about low meadows but recently crossed by boats and ships to those existing in Sweden prevail here also, and there seems good ground for believing that in the days of the Norsemen the White Sea and the Gulf of Finland were joined by a considerable strait. Farther east, again, we have the experience of Murchison and his companions, who found on the banks of the Dwina and Vaga recent shells still retaining their colour, and of the same species as those found in the Arctic Sea. In Spitzbergen, Mr. Lamont reports (see vol. xvii. of the "Quarterly Journal of the Geographical Society") that he discovered recent bones and drift wood several miles inland and high above high-water mark, skeletons of whales thirty to forty feet above the sea level. The seal fishers told him the land was rising, and that the seas thereabouts were now too shallow for the right whale, which had forsaken the Spitzbergen coast. This is confirmed by Malmgren (see Petermann's Mittheilungen, 2, 1863). Farther east we have the Tundras between the Karen Sea and Gulf of the Obi presenting bare desolate flats that look as if they had only recently emerged. Middendorf describes the surface of the great Siberian Tundra as coated with fine sand like that now being deposited by the Polar Sea. Von Wrangel has many useful remarks to prove my position. He tells us that Diomed Island, mentioned by Laptev and Schalaurov, is now joined to the mainland; the coast of the Swatow Ness, which they describe as very indented and ruinous, is now straight. The Bear Islands are mere heaps of ice and stones, evidently but recently covered with water; and shoals and banks now occupy what was tolerably deep water in 1787 when Captain Sarypchev was there.

Herdenstrom, in 1810, found large birches scattered about the Tundra, 3° to the north of any known Siberian forest; probably drift wood such as Wrangel himself found drifting in the Polar Sea. Whales have now almost deserted the Siberian shores, where in the eighteenth century they were common. This is, no doubt, due to the shallowing of the water, as is the case in the Spitzbergen Sea. The shores of the Polar Sea, from the Lena to Behring's Straits, are for the most part low and flat. In winter it is hard to say where land ends and sea begins. A few versts inland, however, a line of high ground runs parallel with the present coast, and formerly, no doubt, constituted the boundary of the ocean. This belief is strengthened by the quantity of drift wood found in the Upper Level, and also by the shoals that run out, and will, no doubt, become dry land (vide Wrangel's Introduction). "At several places along the coast we found old weathered drift wood at the height of two fathoms above the present level of the sea, whilst the lower drift wood lay at a level, indicating a change of level." Moving farther east again across Behring's Straits, we find Captain Beechey describing the coast as a high cliff, now separated from the sea by low flats with bones, &c., on them. I cannot speak with the same confidence of the vast archipelago that bounds America on the north, nor about the northern shores of America, my researches having been confined to Asia, but evidence must abound in the Arctic voyages. Drift wood and bones of whales are mentioned on high ground by several of them. If it be permitted to quote the works of M. Reclus as an authority, and I believe it to be a most sound book, he says, page 628, numerous indications of the phenomenon (i. e. of the upheaval of the circum-

polar land of North America) have been recognised in the Arctic islands, scattered off the coasts of the Continent. At Port Kennedy Mr. Walker found shells of the present period at a height of 557 feet above the sea; a bone of a whale lay at a height of 164 feet. Again, page 651, after saying that Southern Greenland is being depressed, he continues, "On the north of Greenland, from lat. 76°, and in Grennell's land, &c., the directly contrary phenomenon is taking place." Hayes discovered on all the coasts the existence of ancient sea-beaches which had gradually risen to the height of 100 feet.

I have thus shown good ground for entertaining the notion that the land at present rising about the Pole is a continuous area, and is not rising merely in detached masses as M. Reclus's and Mr. Murray's maps (Geographical Distribution of Mammals) would lead us to suppose. I believe, further, that this area, bounded on the south by about the 57th parallel of latitude, is the only area in the Northern Hemisphere which is at present undergoing upheaval. I should feel grateful to any of your correspondents who would point out where there is another area (of course excepting local disturbance immediately round a volcano); or would direct me to any authorities throwing light on the question I have advanced, which for anything I know may be an old theory, or even an exploded heresy.

Not only is the land around the Pole rising, but there is evidence to show that the nearer we get to the Pole the more rapid the rise is. This has been shown most clearly in the case of Scandinavia by Sir Charles Lyell, who most carefully gauged the rise at different latitudes from Scania, where the land is almost stationary, to the northern parts of Norway, where the rise is four feet in a century. While in Spitzbergen and the Polar Sea of Siberia, if in the memory of seal fishers and others the water has shallowed so fast as to have excluded the right whale, we may presume that the rate of emergence continues to increase, until it reaches its focus at the Pole, as it certainly diminishes until it disappears towards the south between the 56th and 58th parallels of latitude. The subject is one of paramount importance to those who are trying to work out the history of the earth, and I once suggested at the British Association that it should be made the work of a special report, but I was snubbed. I appeal with more confidence to you, sir, to help me to ventilate it. The question of the subsidence of other areas, and of the correlated climatic change, I will reserve for another letter.

EBS-002 CIRCUMPOLAR LAND

Howorth, H. H. ; Nature, 5:420-422, March 28, 1872.

After adding some additional observations of land emergence in the Arctic to those in ETB-001, Howorth tries to show that the same sea level changes have occurred around Antarctica.

Having strengthened my former paper by instances of upheaval in other points, and I hope satisfied your readers of the justice of the generalisation about the rise of circumpolar land, it is natural to ask if this remarkable fact is paralleled in any way at the southern pole,—whether we can show that both in the Arctic and Antarctic seas there is a bulging out of the land, and a displacement of the sea at present in progress. Our knowledge of the lands immediately about the southern pole is very scanty; but fortunately we have unmistakeable evidence at the various points of those better known austral lands which approach the antarctic seas, from which we may be justified in drawing a sound conclusion, South America, New Zealand, Australia, Tasmania, and Southern Africa.

To begin with South America, I cannot quote a better authority than Mr. Darwin:-

"Everything in this southern continent has been effected on a grand scale: the land from the Rio Plata to Terra del Fuego, a distance of 1, 200 miles, has been raised in mass (and in Patagonia to a height of between 300 and 400 feet) within the period of the now-existing sea shells. The old and weathered shells left on the surface of the upraised plain still partially retain their colours . . . I have said that within the period of existing sea shells, Patagonia has been raised 300 to 400 feet; I may add that within the period when icebergs transported boulders over the upper plain of Santa Cruz the elevation has been at least 1, 500 feet" (Naturalists' Voyage p. 171). Again, "M. d'Orbigny found on the banks of the Parana, at the height of 100 feet, great beds of an estuary shell now living 100 miles lower down nearer the sea, and I found similar shells at a less height on the banks of the Uruguay; this shows that just before the Pampas was slowly elevated into dry land the water covering it was brackish. Below Buenos Ayres there are upraised beds of sea-shells of existing species, which also proves that the period of elevation of the Pampas was within the recent period" (p. 130). So much for the East Coast. Now for the West. Speaking of the Hacienda of Quintero, in Central Chili, he says:—"The proofs of the elevation of this whole line of coast are unequivocal. At the height of a few hundred feet old-looking shells are very numerous." Again, speaking of Northern Chili, he says:—"I have convincing proofs that this part of the continent of South America has been elevated near the coast at least from 400 to 500 feet, and in some parts from 1,000 to 1,300 feet, since the epoch of existing shells, and further inland the rise may have been greater." In Peru, about Callao, he also found evidences of rising land; but here we come to one of the horizons where rising and sinking land meet. If it be necessary to supplement the account of Mr. Darwin, I have the authority of Mr. Baxendall for stating that he found numerous skeletons of whales and seals stranded above high-water mark on the coast near Africa, where a tide (as is well known to be the case in all the Eastern Pacific) is almost unknown.

Having satisfied ourselves of the rise of the southern portion of South America, we must now shortly state the reasons for making it very recent. Speaking of the earthquake of 1822, which caused a general upheaval of the land, Mr. Darwin says, "The most remarkable effect of this earthquake was the permanent elevation of the land; the land round the Bay of Conception was upraised two or three feet, at the island of Santa Maria (about thirty miles distant) the elevation was greater. On one part Captain FitzRoy found beds of putrid mussel-shells still adhering to the rocks 10 feet above high water-mark; the inhabitants had formerly dived at low-water spring tides for these shells" (p. 310). Again, two years and three-quarters afterwards Valdivia and Chiloe were again shaken, and an island in the Chonos Archipelago was permanently elevated more than 8 feet. At Valparaiso within the last 220 years the rise has been somewhat less than 19 feet, while at Lima a sea beach has certainly been upheaved from 80 to 90 feet within the Indo-human period (*id. passim*). Eighty-five feet above the sea level in an island in the Bay of Callao he found on a sea beach some Indian corn and pieces of Indian thread, similar to those found in Peruvian tombs, a parallel find to that made by Sir Charles Lyell in Scandinavia, which I previously referred to.

Having examined the evidence for South America, we will now turn to the other great southern continent, Africa. I will quote a few passages. "There cannot be the slightest doubt that the upheaval of the country is still going on; for along the whole coast of South Africa from the Cape to Durham Bluff, and still farther north, even as far as Zanzibar, modern raised beaches, coral reefs, and oyster banks may everywhere be seen. At the Izhinluzabalungu Caves is

such a point, where the rising of the coast is plainly visible, recent oyster-shells are now 12 feet and more above high-water mark. The same can be observed on the whole line of the Natal Coast. Van der Decken has observed the same thing at Zanzibar, and is of the same opinion as myself, viz, that the Eastern Coast is rising early in the present year (i.e. 1870). I had the opportunity of observing at the Bazanito Islands about ninety miles north of Inhambane, on the east coast of Africa, a series of raised coral reefs round the island of Marsha containing many living shells and quite recent oyster-banks." (Griesbach, *Geology of Natal*. Quart. Journ. Geol. Soc. xxvii, part ii, p. 69.) Mr. Griesbach also mentions that he saw implements of early man, which were obtained by Richard Thornton and others in old raised beaches of Natal, near Inanda, and at the mouth of the Zambesi River.

Mr. Griesbach is confirmed by Mr. Stow in his papers on the Geology of South Africa in the same Journal (see vol. xxvii, p. 526 et seq.), where bones and teeth are found mixed with shells, quite in a recent state, about Port Elizabeth, &c.

In regard to Tasmania, I quote the following from Mr. Wintle's paper on the Geology of Hobart Town (Mine Journal, vol. xxvii, p. 469):—"Until a very recent period in the geological annals of this island, a great portion of what now constitutes the site of this city was under water. This is proved by the extensive deposits of comminuted shells, all of recent species, which are met with for miles along the banks of the Derwent. Some of these deposits are at an elevation of upwards of 100 feet above high-water mark, and from 50 to 100 yards from the water's edge, plainly showing thereby that a very recent elevation of the land has taken place."

In New Zealand the evidence is the same. M. Reclus says the port of Lyttelton has risen 3 feet since it was occupied by the settlers. Mr. Forbes says that proofs of upheaving of the land are even now obvious to any intelligent traveller. Some of these changes have been witnessed by the present generation. Again, in the Middle Island upheaval of the land is observable in a marked manner through the entire length of the western coast from Cape Farewell to Dusky Bay. Some of the most extraordinary changes in these regions have taken place within the last few years.

This has been confirmed by Dr. Haast, who, however, found some signs of depression at the north-western extremity of the lands. In Australia our evidence is ample:—The north-east, if not the whole of the east coast of Australia, is slowly rising, as proved by the gradual shoaling of the Channel between Hinchinbrook Island and the mainland, due to all appearance neither to silting up nor growth of coral water-worn caves, now well above high-water mark in the sandstone cliffs of Albany Island, and those of the mainland opposite, and in the existence along many parts of the coast, especially towards the north of the peninsula, of extensive tracts of level country now covered with sand dunes, bearing a scanty vegetation, stretching inland 10, 15, and 20 miles off, but which once bordered the sea" (Rattray, *Geology of Cape York Peninsula, Australia*, Mine Journal, vol. xxv. p. 297).

"An immense portion of the continent of Australia is known to be uprising The whole coast round to a distance of several miles inland is covered with recent shells; the drainage of the country is apparently altering. Lakes known to have been formerly filled with salt water are now filling up with fresh or becoming dry. The lagoons near the coast are filled with salt and brackish water, and their banks are filled with marine shells with their colours in many cases preserved. Reefs of rocks are constantly appearing in places where there were none formerly. At Rivoli Bay the soundings have altered so much as to make a new survey requisite. A reef has lately almost closed this harbour. Other reefs have appeared at Cape Jaffa, &c. It would appear that a vast move-

EBS-003 SEALEVEL INDICATORS

ment is taking place in the whole of the south of Australia. In Melbourne the observations of surveyors and engineers have all tended to confirm this remarkable fact. In Western Australia the same thing is observed at King George's Sound, the same, " &c., &c., and so on, for many pages. (See Wood's Geological Observations in South Australia, 135-207, and passim.)

The facts I have enumerated, which might be almost indefinitely multiplied, are sufficient to prove the position that every large mass of land near the South Pole which we can examine shows signs of upheaval, and justifies the conclusion that the circumpolar land is rising at both poles, and that there is a general thrusting out of the earth's periphery in the direction of its shorter axis.

I must modify the opinion expressed in a previous paper that the 57th parallel is the southern limit of upheaval in the northern hemisphere. The limit of upheaval is an irregular line. I believe that the district intervening between the two projecting poles, with its focus along the equator, is an area of subsidence. This conclusion I believe to be of crucial importance in solving both geological and meteorological problems.

Note that a change in the earth's rate of rotation could also cause the distribution of sealevel changes described above. Some of the changes, however, are very large.

EBS-003 [WHALE BONES 330 FEET ABOVE SEA LEVEL]

Anonymous; Nature, 38:134, June 7, 1888.

At a recent meeting of the Scientific Society of Upsala, Dr. C. Aurivillius read a paper on the skeleton of the so-called Swedenborg whale (Eubalena svedenborgii, Lillj.), discovered last November in the province of Halland, in a layer of marl 50 feet above the sea. Remains of this species of whale have only been found once before, viz. early last century, when some parts of one were discovered in the province of Western Gothland, 330 feet above the sea, and 70 miles inland. It was at first believed that they were the bones of some giant, but it is said that Swedenborg discovered their true nature. The skeleton has been presented to the Upsala Museum.

Two possible inferences are that sea level was much higher in recent times or a cataclysmic oceanic surge carried the whale inland.

EBS-004 FOSSIL WHALE IN THE DRIFT

Anonymous; American Naturalist, 5:125, 1871.

The bones of a whale closely allied to the White Whale (Beluga leucas) of the Gulf of St. Lawrence, have been discovered at Cornwall, Ontario County, Canada. It seems to be the same as the B. Vermontana of Thompson.

A possible interpretation here is that the accumulations of drift (supposedly glacial deposits) were actually of marine origin.

SECTION EL: MYTHS AND LEGENDS

The physical records of ancient man are sparse compared to the immense amount of information transmitted across the gulf of time by word of mouth. Messages and hidden meanings probably abound in myth and legend, especially in those of world-wide distribution. The keys to the understanding of this important body of data have apparently been lost, the current tendency being to treat myth and legend with much condescension. Why, for example, detract from ancient man because we have not discovered vast written records. Perhaps memories were better in those days! Such a surmise, however, is not in the spirit of these sourcebooks, which is the avoidance of specific hypotheses. The goal of this section is the gathering in and organization of tales of geological events within the time of man.

- ELC Climate changes. Legends of sharp, extensive changes of climate experienced by ancient man.
- ELD The Deluge. Recountings of the Flood story from various lands and peoples.
- ELG Phantom lands. Legends and stories handed down about islands and great cities, since vanished, and lands still unidentified.

MYTHS AND LEGENDS

ELC-001 RECENT CLIMATIC CHANGES

Howorth, Henry H.; Nature, 6-24-25, May 9, 1872.

In two previous letters I have tried to show that the land is gaining on the sea at both poles; in other words that the periphery of the earth is being thrust out in the direction of its shorter axis. If this change has been so great as to make it probable that the Classical and Arabic accounts were correct when they made Scandinavia an archipelago in the earlier centuries of our era, we may be sure that it has not been without material influence upon other physical phenomena, and notably upon climate.

The increase of land at the poles at the expense of the water will tend to intensify the extremes of temperature in winter and summer, and in consequence, to make the climate much less constant and uniform and much more severe; and we ought to find evidence of this somewhere, if the premisses of my two previous letters are tenable. I wish to adduce a few facts in the way of such evidence, and to ask your correspondents for more either pro or con. Many such must exist.

Greenland is a name which seems ironical under present conditions of climate. It has always seemed to me that the land there has changed its appearance very considerably since that name was applied to it. The Esquimaux were apparently not known as inhabitants of Greenland to the Saga writers. The skzellings they met with were on the coasts of Labrador and farther South. They first appeared after the black plague had nearly destroyed the Norse settlements, and they completed the work the pestilence had commenced. They came from the north, probably from the area now occupied by the so-called Arctic Highlanders. The Indians who now live along the march, or frontier, bounding them and the Esquimaux in North America, have an apparently uniform tradition, that the Esquimaux were formerly not neighbours of theirs, and that they came south across the sea from the islands beyond. I believe that I have sufficient facts by me to justify the opinion that the Esquimaux of both shores of Behrings Straits have been constantly drifting westwards and southwards, and that they are but recent occupants of their present area there. This will appear in a future communication to the Anthropological Institute. These facts are quoted to show that the Esquimaux race has been uniformly leaving its more northern habitat and seeking a more southern one. It is remarkable that the recent Swedish Expeditions to the Eastern Coasts of Greenland found abundance of reindeer and musk-oxen there in areas formerly uninhabited by both animals. This emigration must have come from the north. I can see no adequate cause for a revolution affecting men as well as other animals in such a uniform manner, except the continuously increased severity of local climates which has driven the inhabitants farther south.

Iceland has notoriously become more harsh and untenable in its climate since the days of the Norsemen. I will quote from a capital authority, Henderson's Journal in Iceland, pages 6 and 7:—"It is evident from ancient Icelandic documents that on the arrival of the Norwegians, and for centuries afterwards, pretty extensive forests grew in different parts of the island, and furnished the inhabitants with wood both for domestic and nautical purposes. Owing, however, to the improvident treatment of them, and the increased severity of the climate, they have almost entirely disappeared, and what remains scarcely deserves any other name than that of underwood, consisting for the most part of birch, willow, and mountain ash. That grain was produced in former times in Iceland appears from the names of many places, such as akkrar, akkrances, akkraheron, &c, the word akr signifying a cornfield, and from certain laws in the ancient code,

in which express mention is made of such fields, and a number of regulations are prescribed relative to their division and cultivation." Grain is no longer raised there. The Black Death, and other reasons, have been adduced for this cessation; but these are clearly inadequate causes, the real reason being no doubt the same which has caused grain culture to be discontinued elsewhere, namely, the increased severity of the climate.

What is true of Iceland is also true of Norway, in the most northern parts of which we find many names compounded with the Norse word for barley, proving, as the best authorities agree, that barley then grew where it grows no longer. In Scotland many places show signs of the plough, and of having been sown with cereals where arable farming is now unpractised. It is notorious that not only in Scotland, but even in England as far south as Lancashire, large districts that were once covered with forests are now entirely bare of trees, and not only so, but trees cannot be made to grow there. "The Romans planted vineyards and made wine in parts of England where the hop will now hardly grow."

In Northern Russia beyond the Dwina there is a vast area, formerly known as Biarmia, studded with the graves and other remains of a very prosperous people, whose wealth and civilisation are much descanted about by the Saga writers. Othere, the navigator, whose story was translated by Alfred, tells us that it was on arriving in their country after the dreary voyage round the North Cape, that he first again met with tilled fields and an agricultural race. This area is now deserted except by a few hunters and fishermen; the ancient inhabitants have moved westward and southward into Finland, &c. I have described the migration in a paper to be printed by the Anthropological Institute. The best authenticated case of this desolation is the increased severity of the climate, which makes agriculture almost unendurable there. The Norse traders used to frequent Cholmogorod, the port of Biarmia, in great numbers, both for traffic and for fishing. This navigation continued until the early part of the thirteenth century, when we are told it was gradually put an end to by the increased difficulties with the ice in the White Sea, which becomes practically choked with ice; and when the English found their way to Archangel in the sixteenth century, so forgotten was this old trade, that the journey was treated as one of discovery.

Farther east facts are less accessible. The following quotations from von Wrangel's voyage illustrates my position:-

"In 1810 Hedenstrom went across the tundra direct to Utsjansk. He says, 'On the tundra equally remote from the present line of trees among the steep sandy banks of the lakes and rivers, are found large birch trees complete with bark, branches, and roots. At first sight they appear well preserved, but on digging them up they are found to be in a thorough state of decay. On being lighted they glow, but never burst into flame. The inhabitants use them for fuel. They call them Adamoushtshina (i.e. of Adam's time). The first living birch trees are not now found nearer than 3° to the south, and then only as shrubs.' 'Another cliff, 30 or 35 feet high, beyond the Malaya Kurspat-aschnaja river, consists of ice, clay, and black earth. On drawing out some interspersed roots we found them to be birch, and as fresh as if only just severed from the trees. The nearest woods are 100 versts off.'" These facts show how far to the south the limit of trees has been pushed quite in recent times in Siberia, that is, how much more severe the Siberian climate has become—a fact, perhaps, connected with the persistent south-westerly drifting of Ugrian tribes from this area which has taken place during the historic period. The flora of our own bogs must disclose evidences of some kind on this subject. I should be thankful to any of your correspondents for facts which illustrate the question drawn from this or any other source.

ELD-001 GEOLOGICAL MYTHS

Emerson, B. K. ; Science, 4:328-344, September 11, 1896.

The purpose of Emerson is to explain several persistent myths of mankind in geological terms—the Deluge in particular. The stories and interpretations are charming; and if the reader has problems with spelling and nomenclature he should note that this article was published in 1896. Scientific theories and interpretations change, too. Finally, some of the geophysical phenomena mentioned below are also covered in the Series G sourcebooks.

The Chimaera. In Lycia is a remarkable region, which the inhabitants call Ephestion. The ground is perforated in many places; a fire plays harmlessly without any injury to growing things. It is a pleasant region, therefore, and woody, nothing being injured by the flames.

Strabo says, simply: "The neighborhood of these mountains is the scene of the fable of the Chimaera, and at no great distance is Chimaera, a sort of ravine, which extends upward from the shore." And Pliny, with his accustomed mingling of truth and fiction, says: '—et ipsa (Chimaera saepe flagrantibus jugls' (and Chimaera itself with its flaming peaks). And again: "Flagrat in Phaselide Mons Chimaera et quidem immortalī diebus ac noctibus flamma." Mount Chimaera burns in Phasilis with a certain immortal flame shining by day and by night.) Also: "In the same country of Syria the mountains of Hephaestus, when touched with a flaming torch, burn so violently that even the stones in the river and the sand burn while actually in the water. This fire is also increased by rain. If a person make furrows in the ground with a stick which has been kindled at this fire, it is said that a stream of flame will follow it."

And thus the matter rested until, in the end of the last century, Admiral Beaufort, while anchored off Lycia on hydrographic work, saw each night a strong flame on the peak of a mountain a few miles back from the coast, and was told by the inhabitants that it had always burned there.

He visited the place, and found flames of natural gas issuing from a crevice on a mountain of serpentine and limestone.

In 1842 Spratt and Forbes report as follows on the locality: Near Ardrachan, not far from the ruins of Olympus, a number of serpentine hills rise among the limestones, and some of them bear up masses of that rock. At the junction of one of these masses of scaglia with the serpentine is the Yanar (or Yanardagh), famous as the Chimaera of the ancients, rediscovered in modern times by Captain Beaufort. It is nothing more than a stream of inflammable gas issuing from a crevice, such as is seen in several places among the Apennines. The serpentine immediately around the flame is burned and ashy, but this is only for a foot or two; the immediate neighborhood of the Yanar presenting the same aspect it wore in the days of Seneca, who writes "Laeta itaque regio est et herbida, nil flammis adurentibus."

Such is the Chimaera, 'flamisque armata Chimaera,' deprived of all its terrors. It is still, however, visited as a lion by both Greeks and Turks, who make use of its classic flames to cook kabobs for their dinner.

In 1854 it was visited by the Prussian painter, Berg, who has reproduced the scene in a fine painting now in Berlin. The flame which he says, gives the odor of iodine, is three or four feet high. Several extinct openings were found in a pool of sulphurous water.

The Austrian geologist. Tletze, found the flame two feet across, and a smaller one adjacent. The ruins of an ancient temple of Vulcan, near by and of a late Byzantine church, show how strongly it has impressed the inhabitants in all ages.

The natural phenomenon of a spring which is found by historic documents to have been burning for nearly three thousand years is sufficiently striking, although the slow escape of such gas from Tertiary limestones is not uncommon. The mention of sulphurous waters in the neighborhood may justify us in going back to the same antiquity and drawing from the remark of Theophrastus on the oxidation of pyrite in contact with bitumen, an explanation of the constant ignition of the gas.

Theophrastus says: "That, also, which is called Epinus (or Spelus) is found in mines. This stone cut in pieces and thrown together in a heap exposed to the sun, burns, and that the more if moistened or sprinkled with water."

We may of course assume the more prosaic spontaneous combustion of the volatile hydrocarbons to explain the constant rekindling of the sacred fires.

It remains to consider how the myth and its name arose. The mountain is still called Yanar-dagh, the burning mountain, and in a learned work on coins of Siewon, which reproduces the Chimaera, M. Streber derives the name from the Phoenician word Chamirah, which means the burning mountain.

But the Greek word xapaipa means a goat, and has almost the same sound, and we can see clearly how, as the Greek settlements spread over Lycia, from the north, the meaningless Phoenician names were retained like the Indian names in America, and how the story slowly went back to the fatherland—et crescit eundo—of a strange mountain called Chamira, from which portentous flames escaped, and then of a monster Chimaera, of goat-like form, vomiting flames and ravaging in the mountains of woody Lycia. And so the story was finally fitted for the manipulation of the poets, who little thought they were making the stout Bellerophon run a quixotic tilt against a burning gas well.

The Niobe. Like the Chimaera, the Niobe is an episode in Greek mythology, easily separated from the rest without disturbing the Greek Pantheon. I do not need to describe the great group of the Niobe, the mother weeping over her children, who fall before the shafts of Apollo, which adorns the gallery of the Uffizi at Florence, and forms one of the masterpieces of Greek sculpture, the glory of Scopas or Praxiteles. I do not need to recall the story as told by Homer, how Niobe, the daughter of Tantalus, proud of her twelve children, despised Latona, who had but two; how, therefore, Phoebus and Artemis slew all the twelve with their arrows:

"They lay unburied on the plain for nine days, when Zeus changed them to stone, and on the tenth day the heavenly gods buried them. And now, upon arid Sipylus, upon the rocks of the desert mountain, where, they say, are the couches of the divine nymphs, who dance upon the banks of Achelous, Niobe, though turned to stone, still broods over the sorrow the gods have sent upon her."

And Ovid says:

"She weeps still, and borne by the hurricane of a mighty wind,
She is swept to her home, there fastened to the cliff of the mount,
She weeps, and the marble sheds tears yet even now."

As one climbs from the Gulf of Smyrna, between Mount Tmolus and Sipylus, up the rich valley of the Nif, or Nymphio, there appears, high up in the vertical wall of limestone, the colossal bust of a woman standing on a high pedestal and in a deep alcove. It is cut out of the living rock, like the Swiss lion at Lucerne.

A recess twenty-five feet high and sixteen feet wide has been cut in the rock for the lower part, and a smaller alcove of much greater depth surrounds the bust itself. All the face of the rock around is smoothed, and a broad ledge is

cut around the pedestal to receive the offerings of the ancient Phoenician worshippers of this almost prehistoric statue of the great Mother Cybele, or of Meter Sipylene; gods of the Phoenicians.

From the valley below it makes the impression of a full-length statue with flowing robes, but near at hand the robes are seen to be the very tears of Niobe, formed where the drip of the waters from the limestone roof of the alcove has first struck her cheeks, and running down across her breast has made rippling surfaces of bluish tufa, which has all the effect of tears.

The statue had been greatly corroded, and the stalagmite tears had formed already in the days of Pausanias, who says: "When standing close to it the rocks and precipice do not show to the beholder the form of a woman, weeping or otherwise, but if you stand farther back, you think you see a woman weeping and sad."

And even in the times of Homer the memory of the earlier and vanished worshippers was at best a dim tradition, and the facile imagination of the Greeks had built up the whole beautiful legend, every element of the surrounding scenery adding its portion of suggestion, and it is marvellous how all parts of the story still linger in the valley.

Lot's Wife. Looking down on that most marvellous of all lakes—the Dead Sea, the Lacus Asphaltites of the Romans—the sea of Lot of the Arabs, still stands the great column of salt into which Lot's wife was changed.

"She was changed into a pillar of salt," says Josephus, "for I have seen it, and it remains to this day."

And Irenaeus explains how it came to last so long with all its members entire, because "when one was dissolved it was renewed by miracle." It was, in fact, the geological miracle of erosion.

The column looks down from the plain of Sodom, and on the great southern bay of the sea, ten miles square, and but one or two feet deep, where sulphur, deposited by many hot springs, is abundant in the clay, and where bitumen oozes from every crevice of the rock, and every earthquake dislodges great sheets of it from the bottom of the lake, where the Arabs still dig pits for the 'stone of Moses' to gather in, and sell it in Jerusalem, and where, in that most ancient fragment of the Pentateuch, four kings fought against five, and the kings of Sodom and Gomorrah slipped in the slime-pits and fell. One who has read of the burning of an oil well or Oil Creek, or in Apscheron will have a clear idea of the catastrophe which overtook the cities of the plain where the Lord rained upon Sodom and upon Gomorrah brimstone and fire out of Heaven.

Following the latest extremely interesting researches of Blankenkorn, we may picture the upper cretaceous plateau of Judea—an old land, cleft at the end of the Tertiary by many faults, between which a great block sank to form the bottom of this deep sea. It carried down in the fossiliferous and gypsum-bearing beds the source of the bitumen and the sulphur. We may picture the waters standing much higher than now during the pluvial period, which matched the northern glacial period, rising nearly to the level of the Red Sea, but never joining it. In the succeeding arid interglacial period, the time of the steppe fauna in Europe, the sea shrank to within a hundred meters of its present level, and deposited the great bed of rock salt which underlies the low plateaus around its southern end. The advent of the second glacial period was here the advent of a second pluvial period, which swelled the waters and carried the bitumen-cemented conglomerates over the salt beds to complete the low plateau. After the second arid period with some lava flows, and a third pluvial period with the formation of a lower and broader terrace, the waters shrank to the present saturated bittens in the present arid period. In the earlier portion of this last

or post-glacial stadium, a final sinking of a fraction of the bottom of the trough, near the south end of the lake, dissected the low salt plateau, sinking its central parts beneath the salt waters, while fragments remain buttressed against the great walls of the trench forming the plains of Djebel Usdum and the peninsula El Lisan, with the swampy Sebeha between. Imagine a central portion of one of the low plains which extend south from the 'Finger Lakes' to sink, submerging Ithaca or Havana in a shallow extension of the lake waters. It exposed the wonderful eastern wall of Djebel Usdum, seven miles long, with 30-45 m. of clear blue salt at the base, capped by 125-140 m. of gypsum-bearing marls impregnated with sulphur, and conglomerates at times cemented by bitumen. It was this or some similar and later sinking of the ground, at the time when geology and history join, which, with its earthquakes, overthrew the cities of the plain and caused the outpour of petroleum from the many fault fissures and the escape of great volumes of sulphurous and gaseous emanations, which, ignited either spontaneously, by lightning or by chance, furnished the brimstone and fire from heaven, and the smoke of the land going up as the smoke of a furnace which Abraham saw from the plains of Judea.

But with Lot's wife the case is different. The bed of salt out of which she was carved, and has been many times carved, was exposed by the very catastrophe which destroyed the cities; and Lot fled to Zoar in a direction opposite to that in which the salt bed lies. As Oscar Fraas found his Arabs calling the salt pyramid 'Lot's column,' so, in early times, when the tradition of the burning cities was gradually growing into the myth of Sodom and of Lot, some old name of the salt column, grown meaningless, may have had such sound as to suggest the term, 'Lot's wife'—Bint Sheck Lut, or the woman's own name in the current language, as Chamirah, the burning mountain, suggested Chamaera, the goat, and the answer to the question why was the salt column called Lot's wife was quickly given and woven into the legend. In that dry climate successive erosions have reproduced it along the seven-mile ridge of salt, still called Kashum Usdum, or Sodom.

The Flood. Only through an exegesis of the German words Alluvium and Diluvium would the young geologist be reminded of the time when the Flood was a burning question in geology, an igneo-aqueous question, so to speak; when commentaries explained the fossil shells in the Apennines as due to Noah's Flood, and Voltaire tried to break the force of this important proof of the truth of the Bible by declaring these shells to be the scallop-shells thrown away by expiring pilgrims of the Crusades; when Andreas Scheuzer apostrophized his fossil salamander.

It was thus a great surprise when one of the most powerful and philosophical works of the century on geology, 'Die Ansicht der Erde,' of Suess, had as its opening chapter an explanation of the Flood as due to a coincidence of a cyclone and an earthquake at the mouth of the Euphrates. The Biblical account is plainly exotic, told by a people ignorant of sea-faring—a fresh-water account of a salt-water episode. The description of the vessel as a box or ark, the going in and shutting the doors, and the opening of the windows, remind one of a house-boat and indicate the adaptation of the story to the comprehension of an inland people. Its minor discrepancies and blending of the Jahvistic and Elohist elements show the story has come by devious courses from a distant source.

The account of the Chaldean priest, Berossus, 250 B. C., located the occurrence at the mouth of the Euphrates, where the native boatman still pitches his boat within and without with pitch, as the ark was pitched.

Berosus, priest of Bel, quoted by Alexander Polyhistor, says that the Flood occurred under the reign of Xisuthros, son of Otlartes. Kronos announces to Xisuthros, in a dream, that on the fifteenth of the month Daisios all mankind

shall be destroyed by a flood. He commands him to bury the writings containing the records of the history of his country at Sippara, city of the dead, then to build a vessel, to stock it with provisions, then to embark with his family and his friends, also to take quadrupeds and birds with him.

Xisuthros obeys the command. The Flood occurs and covers the land; it decreases; he lets out birds to gain knowledge of the state of things, and finally leaves the ship and prepares with his family, an offering to the gods. Xisuthros is then, for his piety, translated to live among the gods, with his wife, his daughter and the steersman. Of the ship of Xisuthros, which finally stranded in Armenia, there still remains a portion in the Cordyaian Mountains in Armenia, and the people scrape off the bitumen with which it is covered, and use it as an amulet against sickness. And as the others had returned to Babylon and had found the writings at Sippara they built towns and erected temples, and so Babylon was again peopled.

Twenty years ago George Smith excavated and translated the inscribed tiles of the library of Asurbanipal, King of Assyria, 670 B. C., who, at the time of the founding of Greece, was gathering copies of the sacred writings of the ancient cities of Asia. The historical books of this library carry the annals of the Babylonians back 3800 B. C., but contain no certain account of any flood. How remote must then have been the great catastrophe which had filtered down in tradition and become embalmed in sacred myth and stately poem before the dawn of history! I present here, after the latest translations of Haupt and Jensen, the last but one of the cantos of the Gilgames Epic, corresponding to the eleventh sign of the zodiac, Aquarius (or month of the curse of rain), containing the story of the flood.

Gilgames (Nimrod), the hero of Urruh, leaves his native town sick and troubled by the death of his friend Eabani, and visits his ancestor Samasnapisthim (Xisuthros) called Hasisadra (the devout wise man). Hasisadra spoke to him, to Gilgames, "I will make known unto thee, O Gilgames, the hidden story, and the oracle of the gods I will reveal to thee. The city of Shuripak,—the city which, as thou knowest, lies on the bank of the river Euphrates—this city was already of high antiquity when the gods within set their hearts to bring on a flood storm (or deluge). Even the great gods who were there— their father Anu; their councillor, the warlike Bel; their throne-bearer, Adar; their prince, Ennugi. But the Lord of unfathomable wisdom, the god Ea (the god of the sea), sat alone with them in council, and announced their intention unto the field, saying, Field! town! field! hear! town!; give attention, O man of Shurippak, son of Ubara-Tutu (The splendor of the Sunset, Lenarmont, Sayce). Destroy thy house, build a ship, save all living beings which thou canst find. Withdraw from what is doomed to destruction. Save thy life and bid the seed of life of every kind mount into the ship.

"The vessel which thou shalt build, 600 half cubits in length, shall be her shape, and 120 half cubits the dimensions for both her width and depth. Into the sea launch her. When I understood this, I spake unto the god Ea—My lord thy command which thou hast commanded, I will regard it, I will perform it, but what shall I answer the city, the people, the elders? (The young men and the elders would ridicule me.)

"The god Ea opened his mouth and spake unto me, his servant 'And thou shalt thus say unto them, "I know the god Bel (the god of Shurippak) is hostile to me, so I cannot remain in(the city); on Bel's ground I will not rest my head. I will sail into the deep sea; with the god Ea, my lord, I will dwell." But upon you there will pour down a mass of water. Men, fowl, and beast will perish, the fish only will escape. *** And when the sun will bring on the appointed time Kukki will say, "In the evening the heavens will pour down upon you destruction."

"Then, however, close not thy door until the time comes that I send thee

tidings. Then enter through the door of the ship, and bring into its interior thy food, thy wealth, thy family, thy slaves, thy maidservants and thy kindred. The cattle of the field, the wild beasts of the plains***will I send you, that thy gates may preserve them all. '

"Hasisadra opened his mouth and spake. He said to Ea, his lord 'No one has ever built a ship in this wise on the land. However, I will see to it, and build the ship, as thou hast commanded.' (The description of the building of the vessel very partial.) I built the ship in six stories. I saw the fissures, and added that which was lacking. Three sars of bitumen I poured upon the outside. (Thirteen lines of description illegible.) The vessel was finished. All that I had I brought together, all that I had in silver I brought together. All that I had of gold I brought together. All that I had in living seed I brought together. And I brought all this up into the ship, all my manservants and my maidservants, the cattle of the field, the wild beast of the plain, and all of my kindred, I bade embark.

"And now the sun had brought on the appointed time, a voice spake: 'In the evening the heavens will rain destruction. Enter into the interior of the ship and shut the door. The appointed time is come. ' The voice said, 'in the evening the heavens will rain destruction. ' With dread I looked forward to the going down of the sun. On the day appointed for embarking I feared (grestly). Yet I entered into the interior of the ship and shut to my door behind me to close the ship. To Bazurbil, the steersman, I gave over the great structure with its load. Then arose Museri-ina-namari from the foundations of the heavens; a black cloud, in whose middle Ramman (the weather god) let his thunder roar, while Neba and Sarru rush at each other in warfare.

"The Throne-bearers stalk over mountain and land,
The mighty god of pestilence let loose the whirlwinds (?)
Adar lets the canals overflow unceasingly.
The Anunnaki raise their torches,
They make the earth glow with their radiant gleams.
Ramman's Inundating wave rises up to heaven,
All light sinks in darkness.
In a day they lay waste the earth like a plague, the winds raging blow.
Mountain high they bring the waters to fight against mankind.
The brother sees the brother no more,
Men care no more for one another.
In heaven the gods fear the deluge and seek refuge.
They mount up to the heavens of the god Anu.
Like a dog in its lair the gods crouch at the windows of heaven.
Istar (the mother of mankind) cries like a woman in childbirth,
The sweet-voiced queen of the gods cries with loud voice:
'The dwelling place of mankind is reduced to slime.
That has come which I announced before the gods as an approaching evil.
I have announced the evil before the gods,
The war of destruction against my children have I announced.
That which I brought forth, where is it. It fills the sea like fish spawn. '
Then the Gods wept with her over the doings of the Anunnaki.
They pressed their lips together.

"Six days and six nights the wind and the deluge and the storm prevailed. At the opening of the seventh day, however, the storm lessened, the hurricane, which had waged a warfare like a mighty army, was appeased, and storm and deluge ceased. I sailed the sea mourning that the dwelling-places of mankind were changed to slime. Like logs the bodies floated around. I had opened a window, and as the light of day fell upon my face I shuddered and sat down

weeping. My tears flowed over my face. Wherever I looked was a fearful sea. In all directions there was no land. Helpless the ship drifted into the region of Nizir. There a mountain in the land Nizir held the ship stranded, and did not allow it to advance farther toward the heights. On the first and second day the mountain of Nizir held the ship. Also on the third and the fourth day the mountain of Nizir held the ship. Even so on the fifth and the sixth day the mountain of Nizir held the ship. At the approach of the seventh day I loosened a dove and caused it to go forth. The dove went, it turned, and it found not a place where to rest, and it returned. I loosened and I caused to go forth a swallow. It went, it turned, and it found not a place where to rest, and it returned. I loosened and I caused to go forth a raven. The raven flew off, and as it saw that the water had fallen it turned back. It waded in the water, but it returned not.

"Then I caused all to go forth to the four winds, and made a sacrifice. I erected an altar on the peak of the mountain. I disposed of the measured vases, seven by seven; beneath them I spread seeds—cedar and juniper. The gods smelled the odor. The gods smelled the good odor. The gods gathered like flies above the master of the sacrifice. From afar then the goddess Istar at her approach raised the great bows that Anu had iriade as their glory. She said, 'By the ornaments of my neck never will I forget. These days will I remember and never will I forget them forever. May the gods come to my altar. Bel shall never come to my altar, because he has not controlled himself, and because he has made the deluge, and my people he has given over to destruction.'

"Bel also, at his approach, saw the vessel from afar. Bel stood still; he was full of anger against the gods and the god-like ones.

"What soul has then escaped?

"Never shall man survive the destruction.

"Adar opened his mouth and he spake. He said to the warrior Bel;

"'Who, also, if it be not Ea, can have planned this? And Ea knew and has informed him.' Ea opened his mouth and spake. He said to the warrior Bel: 'Thou herald of the gods, warrior, why hast thou not controlled thyself; why hast thou made the deluge? Visit upon the sinner his sin, upon the blasphemer his blasphemy. Be persuaded not to destroy him. Be merciful that he be not destroyed. Instead that thou shouldst make a deluge, let the lions come, and let them cut off men. Instead that thou shouldst make a deluge, let the hyenas come, and let them devour men. Instead that thou shouldst make a deluge, let the famine come and destroy the land. Instead that thou shouldst make the deluge, let the god of pestilence come and destroy the land. I have not disclosed the decision of the great gods. Hasisadra has interpreted a dream, and has understood the decision of the god.' Then Bel came to a better mind. He mounted to the interior of the vessel; he took my hand and made me to rise; myself made he to rise. He made my wife to stand up, and put her hand in mine; he turned around to us and blessed us.

"Hitherto Hasisadra was mortal, and behold, now, Hasisadra and his wife are lifted up to the gods. He shall dwell far away at the mouths of the rivers.'

"They took me, and in a secluded place at the mouths of the rivers they made me abide."

Surippak, the home of the wise man, on the banks of the Euphrates, of high authority before the deluge, is the same as Sippara, where Xisuthros (Hasisadra), according to Berosus, buried the holy writings before the flood. Its ruins have been found in the Hill of Abu-Habba, about halfway between Babylon (now Hilleh) and Bagdad.

It was 'at the mouths of the rivers;' that is, in the time of the poem, the Euphrates and the Tigris emptied separately into the Persian Gulf. Now the Schat el Arab, formed by the union of the two streams, empties into the gulf, perhaps 400 kilometers below the site of the ancient city, across a delta so low

and flat that the tide runs up 300 kilometers, and at Old Ninevah the elevation is only 300 m. Delitsch has collected the evidence that the two streams once flowed separately into the gulf. Pliny says that almost nowhere does the formation of land by a stream advance so rapidly as here. He mentions a town, Alexandria-Antiochia, which, in the third century B. C. , was about 1,600 m. from the sea, and had its own harbor, and 300 years later was 33 kilometers inland. Other historical documents make it probable that the streams were separate 150 years B. C. Rawlinson says that the delta advanced 3.2 kilometers in 60 years. All the attendant circumstances accord with this location of the story. Here, among a maritime people, as connoisseurs, they ridicule the building of a ship on the land. Ea is the goddess of the sea. And it is marvelous that this trait of the original is preserved in the Koran, where the story is told at length- "And he made the ark, and as often as the elders of the people came by him they ridiculed him, and he said, 'If you rail at us, be sure that we shall also rail at you as you rail at us. '"

From the time of Moses and the Tower of Babel, pitch or bitumen had been much used in the Euphrates valley, where the Tertiary marls produced it abundantly. In Genesis xi. 3, it says of the Tower of Babel, "slime had they for mortar," and a primitive folk still pitches its boats inside and out on the waters of the Euphrates.

Thus the starting-point of the ark is well ascertained, and its landing-place can also be quite clearly located. It was in the land of Nizir, says the record. The Mesopotamian lowland is a narrow, northward extension of the Persian Gulf, between the Arabian plateau on the west and the Zagros Mountains, the scarp of the Persian highlands, on the east. An inscription of Asurnacirpal, from the same library, reads: "Left Kalzu (by Arbela) and entered the region of the town of Babite, and approached the land Nizir." This is the account of a military expedition, and it followed up the great war road, by which, 500 years later, Darius Codomanus fled from the armies of Alexander. The region of Nizir was east of the Tigris, at the foot of the Zagros chain, 300 feet above the sea, and the craft of Hasisadra must have been swept 160 miles north-east, and stranded in the foothills on the valley border.

Early accounts placed this landing on Mount Judi, in southern Armenia, where a temple in its honor was built in 776 A. D. Berosus places it in the Cordyaean Mountains of Armenia, Genesis in Mt. Ararat (Araxes). It is remarkable how the tradition had clung to this grand volcano. The people still tell of the wood and pitch being carried from the ark as amulets, and dare not attempt to ascend the sacred mountain, and disbelieve the accounts of those few foreigners who have reached the summit. Indeed, a Constantinople newspaper account of a scientific commission sent out by the Turkish government in 1887, to study the avalanches in the mountain, tells of the finding of the ark, encased in the ice of a glacier on the mountain.

We may contrast the Chaldean and Biblical accounts in several matters. The sending out of the birds and the bow in the heavens join with many other points to prove the identity of the stories.

In many ways the Biblical account is modified to suit the comprehension of an inland folk. While the Gilgamesh epic describes a violent hurricane and inundation, which expended its force in six days, the Biblical account describes a long-continued rain of forty days, or, in the Elohist document, of one hundred and fifty days. "And the waters were dried up from off the earth, and the face of the ground was dry." In the epic the forests were destroyed, and the face of the earth reduced to slime.

Waters rising from great rains would have swept the ship down the valley, while the epic makes it go from the gulf northeast to the region of Nizir. And, indeed, what seems the better translation of the Noachian account agrees with

this. Gen. vi. 17, "I do bring a flood of waters" is better translated "I do bring a flood from the sea," and Gen. vii. 6, "Noah was six hundred years old as the flood of waters" (or better, 'from the sea') "arose." As Amos says writing 'two years after the earthquake.' "Seek him that maketh the day dark with night, that calleth forth waters of the sea, and poureth them out upon the face of the earth."

We may now try to strip the account of its abundant personification, and see how far it is susceptible of a possible or probable translation into scientific language.

There are, first, the warnings. Hasisatra, the wise man, and, we may assume, wise in the ways of the sea, stands on the shore of the ancient harbor-town, Surippak, and receives the warnings of Ea, goddess of the sea. These were the unusual swellings of the sea from small premonitory earthquake shocks beneath the waters. There is next added a voice, or noise, a more unusual warning, not personified. This may have been the rumbling which may precede any severe earthquake. It is a region where earthquakes are antecedently probable. From the circle of fire that surrounds the Pacific, a zone of seismic activity connects the East and West Indies by way of the Mediterranean, and passes this region. The volcanic area of northern Mesopotamia and Syria is in seismic activity much of the time. Many towns have been several times destroyed and hundreds of thousands of people have been killed. And the recently sunken areas of 'Lemuria' to the south indicate a region of profound faulting apt for the production of earthquakes.

In the/Egean the sinking of the great land blocks by which the sea was formed is so recent that it is embalmed in the Greek mythology; Poseidon, god of the sea, ever warring victorious against the gods of the land. And, though rarely noted on the lower Euphrates, earthquakes and seaquakes, as the Germans say, are not rare across the northern parts of the Indian Ocean; the wise man accepts this warning of impending danger and builds a great craft for the safety of his home, and with the increase of the threatenings embarks his family, regardless of the ridicule of the townsfolk.

"Then arose from the foundations of the heavens a black cloud, in whose middle Ramman (the god of storms) lets his thunders roar, while Neba and Sarru rush at each other in battle. The throne-bearers stalk over mountain and plain." These latter are the great slow-moving sand columns (whirlwinds) which precede and hang on the borders of the coming storm. They still occur around Bagdad, change day into night, and extend over the whole valley of the Euphrates. "The mighty god of pestilence lets loose his hurricanes." So far it is the description of the oncoming of a mighty storm. Then follow elements which may be interpreted as earthquake phenomena. The Biblical account says the foundations of the great deep were broken up, and at the end they were stopped. This may be explained as the uprush of the ground waters, so marked at Charleston and New Madrid, on the Indus plain, at Lake Baikal, where a lake ten by fifteen miles was formed, and in the delta of the river Selenga, when the fastenings of the wells were blown into the air like the corks of bottles. "The Annuniki raise their torches; they make the land glow with their radiant gleams." The Annuniki are the gods of the underground, the gnomes or kobolds of German saga, and their raising their torches is the inflaming of the natural gases, so common in these bituminous Tertiary beds, in the fissures opened by the earthquake—a frequent occurrence also in similar regions on the Caspian.

In the earlier translation by Haupt the suggestions of earthquake intervention were even more striking than in the later translations. "Adar lets the canals overflow unceasingly. The Annuniki bring floods from the depths. They make the earth tremble by their might." Although hurricane inundations have

overwhelmed great areas of land, the earthquake wave is in many ways a mere probable agency here for the production of a flood, exceptional as this must have been to have impressed itself so deeply on this ancient folk. We recall the Lisbon earthquake wave; how the United States warship *Monongahela* was carried ashore in 1863, at Santa Cruz, and landed on the tops of the houses; or how the great seismic wave of 1868 carried the *Wateree* in the harbor of Arica, Peru, seven or eight miles inland, landing her in a tropical forest, where she ended her days as a hotel, while her consort, the *Fredonia*, rolled over and over, and sank with all on board; or the last terrible earthquake waves in Japan and China.

The account then advances strongly to its climax and catastrophe. "Ramman's floodwave mounts up to heaven." All light sinks in darkness. Terror overcomes gods and men. "Like dogs in their lair the gods crouch at the windows of heaven." This is the description of the incoming of the great cyclonic waves, perhaps reinforced by earthquake waves, for when the seismic tension has just come to equal the resistance the great additional strain caused by the relief of pressure of the low barometer of the cyclone has not infrequently set loose the impending earthquake. Of 64 hurricanes in the Antilles 7 were accompanied by earthquakes. In the Bay of Bengal the cyclones average one a year and destroy a million people in a century; and once at Calcutta, in 1737, when the waters rose 40 feet, 14 ships were carried over the trees and 300,000 people were killed; and on the Kistna in 1800 the cyclone and the earthquake occurred together. Indeed, several of these cyclones have been traced across into the Persian Gulf, and one in 1769 was accompanied by an earthquake on the lower Euphrates—the very site of the ancient myth. On the broad plains of the Punjab are many indications of similar inundations. I travelled, said Ibn Batuta (1333), through Sind to the town Sahari, on the coast of the Indian Sea, where the Indus joins it. A few miles from here are the ruins of another town, in which stones in the form of men and animals in almost innumerable amount occur. The people were so sinful that God changed them to stone and their animals and their grain. It is interesting to observe the different effects these disturbing events have upon people of different grades of culture.

In 62 A. D. Oppolonius of Tyana, at Phaestus, in Crete, was preaching to a company of worshippers of the local deity, when an earthquake arose. "Peace," he said, "the sea has brought forth a new land." An island was found between Thera and Crete, Santorin, beloved of all geologists in modern times. The crowd loses all judgment in wonder and admiration.

A true flood panic occurred in the time of Charlemagne. Stöffler, a celebrated astronomer and professor of mathematics at Tübingen, found, as the result of abstruse calculation, that the earth would be destroyed by a flood in 1524. The news spread rapidly and filled Europe with alarm. In Toulouse an ark was built by advice of the professor of canonical law to rescue at least a part of the people. Indeed, in our own days, Prof. Rudolph Falb and similar prophets announce a new flood in the year A. D. 7132. And Falb has by his unverified earthquake predictions caused panics in Athens and Valparaiso.

It is the western migration of this ancient story that is noteworthy, and its association with the punishment of sin by the religious genius of the Hebrews which has made it world-wide. Such myths of observation, dependent on local floods or the suggestion of fossils, are most widely spread, and they find place in cosmogonic myths—explanations of the origin of land and sea; national myths—explanations of the origin of peoples; and myths of destruction of land or people, with or without the idea of punishment for sin.

They are wanting among the Africans and in Australia and Oceania accord-

ing to Lenormant: more accurately among the Papuans of Oceania, for the Feejee Islanders kept great canoes on the hill-tops for refuge when the flood should return.

In China the great Cyclopaedia (2357 B. C.) says: "The waters of the flood are destructive in their inundation. In their wide extent they surround the mountains, overtop the hills, threaten the heaven with their waters, so that the common folk is dissatisfied and complains. Where is the able man who will undertake to control the evil. Kwan tries nine years, Yu eight years. He completes great works, cuts away woods, controls the streams, dykes them and opens out their mouths. He feeds the people."

This refers to the 'Curse of China,' the Yang-ze-Kiang, which flows sometimes into the Gulf of Pechili north of the promontory of Shantung, sometimes to the south of the Yellow Sea.

Our own Indians gave Catlin 160 flood myths. The dog of the Cherokees is well known. On Cundinamarea in Mexico there were four destructions: of famine, personified by giants; of fire, by birds; of wind, by monkeys; of water, by fishes.

The Quiches of Guatemala say: As the gods had created animals who do not speak or worship the gods and had made men from clay who could not turn their heads—who could speak indeed, but not understand anything—they destroyed their imperfect work by a flood.

A second race of mankind was created, the male of wood, the woman of resin, but it was not thankful to the gods. The gods rained burning pitch on the earth, and sent an earthquake, destroying all but a few, who became monkeys. A third attempt succeeded so well that the gods themselves were terrified at the perfection of their work, and took from them some of their good qualities, and the normal man resulted.

The Arawaks of British Guiana and Venezuela were for their sins twice destroyed—once by flood, and once by fire, and only the good and wise were saved.

The flood is a perennial blessing in Egypt, and when the Greeks told the priests of the deluge of Deucalion they said, 'Egypt has been spared this.'

There is an inscription on the walls of the tomb of Seti-on, in Thebes, 1350 B. C. The sun-god, Ra, is wroth with mankind, and the council of the gods decree its doom. Hathor, queen of the gods, does the work, till all the land is flooded with blood. She sees the fields flooded with blood, she drinks thereof; her soul is glad; she does not know mankind. Only those who, at the right time, fix their thoughts above are spared, and of these the Majesty of Ra says: 'These are the good.'

In Persia there are no flood myths preserved before time of Zoroaster.

In India, where the flood is a constant scourge, the four Yugas (ages) and the four Manvartaras, the alternate destructions and renewals of the human race, are Vedic myths, and no trace of the flood story appears in the Vedas. The Satapatha-Bramahna, written just before the time of Christ, is especially interesting, from the blending of the Chaldean account with the Indian mythology. In this oldest account the flood came from the sea, the warning and the rescue of Manu, the Indian Noah, from Vishnu, in form of a fish. Here all the suggestion may be indigenous. There is no punishment.

In the Mahabharata the ship lands on the highest peak of the Himalaya. In the last part of the story, in the Bhagarata Purana, the motive of the flood is that the wickedness of man was great in the earth. Vishnu, in the form of a fish, warns Manu Satjavrata, the well-doer (Ea was a fish-god in the Chaldaean story, and Oannu, in Berosus, was a fish-god), that in seven days the three worlds will sink in an ocean of death, but in the midst of the waves a ship will be provided for Manu. He is to bring all useful plants and a pair of all irra-

tional animals into the ship. The sea rose over its banks and overwhelmed the earth. Violent wind and cloudburst from measureless clouds contributed to the flood. Vishnu, in form of a gold-gleaming fish, guided the ship. Before the flood the holy Vedas were stolen, afterwards they were restored by Vishnu.

In Greece, also, as the sinking of the land has persisted to greater extent into the most modern times, so the flood-myths have there greater variety and definiteness than elsewhere, and later the Chaldaean account was grafted on to the earlier with greater fulness. The story is not known to Hesiod in the 'Works and Days' (8th century B. C.), though he enumerates several destructions of the sinful race of man, and the 'Iliad' mentions destructive cloudbursts as the usual punishment of heaven on the unjust judge.

Thus, in the Boeotian myth Ogyges, it is significant that Ogyges was son of Poseidon, god of the sea, and I have heard the name itself derived from an Aryan root, meaning a flood. Ogyges is rescued in a boat.

The story of Deucalion's flood is first given in the Hesiodic catalogues, 800 to 600 B. C. Pyrrha and Deucalion were alone rescued in a ship. As gold in an archaic form by Pindar (500 B. C.), 'Pyrrha and Deucalion, coming down together from Parnassus, founded their mansion first, and, without marriage union, produced the strong race of the same stock, and hence they were called Laioi from a word meaning stones, as they threw stones over their heads to form the first men.

Apollodorus (100 B. C.) shows the first influence of the Semitic myth. He extends the flood over almost all Greece, and says Deucalion offered sacrifice on leaving the ship. Later, the ark, the taking-in of animals and sending-out of birds, appear in the Greek myth, and Lucian, or pseudo-Lucian, in "De Dea Syria" (160 A. D.), in a chapter on Hydrophoria, narrates an Armenian flood-myth, which had its home in the upper Euphrates, at Hierapolis, the modern Mambedj, and blends the Hellenic and Semitic story. "The most say that Deucalion Sysythes built the sanctuary, that Deucalion under whom the great deluge occurred. Of Deucalion I heard also in Hellas the story which the Hellenes tell of him, which runs as follows: The first men had grown very wicked upon the earth, and, in punishment, suffered a great evil. The earth sent up from its bosom mighty masses of water. Heavy rains followed, the rivers swelled, and the sea overflowed the land, until all was covered with water, and all were destroyed; only Deucalion, of all mankind, remained alive. He had built a box or ark, and his family, as also pairs of all kinds of animals, entered into it. All sailed in the ark as long as the waters continued. So the Hellenes write of Deucalion. To this the inhabitants of the holy town add a very strange story; that in their land a great fissure opened in the earth, and this received all the water. Deucalion built altars after this happened, and by the opening built a temple to Here. I saw the opening. It is under the temple, and is very small. As a sign and remembrance of this story, they do as follows: Twice a year water is brought to the temple from the sea. Not alone do the priests bring this; out of all Syria and Arabia, India, and from beyond the Euphrates many go down to the sea, and all bring water. They pour it out in the temple, and it flows into the fissure, and the small opening receives a great quantity of water. And this ceremony, they say, Deucalion appointed in the temple in remembrance of the catastrophe and his rescue. A statue of Here is in the temple, and another god, which, although it is Zeus, they call by another name. Between the two stands a golden column. The Assyrians call it the sign, give it no special name, and cannot explain its origin or its form. Some refer it to Dyonyusus, others to Deucalion, others to Semi rami s. There is on its top a golden dove. Therefore, it is said to represent Semiramis. Twice a year it is taken to the sea to bring water, as described above." There were similar Hydrophoria at Athens.

ELD-002 TRADITIONS OF THE DELUGE

Restelle, William; Biblioflieca Sacra, 64:148-167, 1907.

The Deluge, if it really did transpire, must have been of geological significance—mass extermination and extensive deposits of debris should have occurred. Such evidence is in the geologists' legitimate province. However, since the Deluge supposedly transpired during the time of man, legend and tradition may preserve some useful facts.

Researches during the nineteenth century into the languages, myths, and racial characteristics of various peoples have disclosed many interesting facts bearing upon the early history of mankind. Races, separated from each other by vast bodies of water, varying in their degrees of civilization and differing in their modes of life, betray their historical relations to each other by their languages and traditions. The nursery tales, which we delighted to listen to in our childhood days, are related by mothers to attentive ears among all the Aryan peoples, among the Hindoos and Chinese, and even among the Redmen of North America, and the blacks of tropical Africa. Legends which we used to accept as true and thought were peculiar to our own chronicles are told and re-told with certain modifications in countries far distant from ours. But of all the traditions and myths found in the records of the past, or among the living races of to-day, that of the Deluge is the most remarkable. The story of a great cataclysm which swept mankind from off the face of the earth, allowing only of the providential escape of from two to eight persons, who afterwards re-peopled the world, is, with only two exceptions, found among all races, ancient or modern. These stories of the Flood, though substantially the same, all possess considerable human interest, varying, as they do, in their form of narration. Many of them are graphically told and embellished with the wildest imagination.

The oldest and most remarkable narrative of the Deluge is undoubtedly the one discovered a quarter of a century ago by Mr. George Smith in his excavations in Assyria. The whole story of this great event is narrated in an epic found on some cuneiform tablets exhumed at Nineveh, and is as follows:-

The god Hea appeared to Xisuthrus, a Chaldean king, in a dream, and warned him that all flesh should perish in a great flood. The god bade him take all the sacred writings, and bury them in Sippara, the City of the Sun; then build himself a huge ship, store therein a large quantity of provisions and "cause to go up into the vessel the substance of all that has life," his family and his most intimate friends. Xisuthrus obeyed. When all had been prepared, the waters belched forth from their caverns and overwhelmed the earth.

"The archangels of the abyss brought destruction—in their terrors they agitated the earth. The inundation of Ramman swelled up to the sky—and the earth became without lustre, was changed into a desert. . . . Brother no longer saw his brother. . . . Six days and as many nights passed, the wind, the water-spout, and the diluvian rain were all in their strength. At the approach of the seventh day the diluvian rain grew weaker, the terrible water-spout—which had assailed after the fashion of the earthquake—grew calm, the sea inclined to dry up and the wind and the water-spout came to an end. I looked at the sea, attentively observing—and the whole of humanity had returned to mud. I opened the window, and the light smote on my face. I was seized with sadness; I sat down and wept."

Thus does the hero of the poem passionately relate his experience. The ship stranded on Mount Nizir, but the waters abated not. The seventh day after the ship had stranded, Xisuthrus sent out a dove, and later, a swallow, both of which

returned. He then loosed a raven, which did not return, for it fed and rested on the floating carcasses of animals. Xisuthrus now built an altar on the peak of the mountain, and offered up sacrifice unto heaven. The deities accepted his offerings, and gave ear unto his supplication, for in answer to his prayers they caused the waters to subside, and commissioned Bel to enter the vessel, and carry to their reward Xisuthrus and the few pious souls who were spared the awful curse which befell the rest of humanity.

There are two versions of the Babylonian account, thought to be due to the existence of two different documents. The one I have here epitomized is derived from those cuneiform tablets recently exhumed at Nineveh, and is doubtless the more authoritative. The other version comes through Berosus, an historian of Chaldea, and a contemporary of Alexander the Great, who apparently possessed important documents from which he obtained a description of the Deluge. According to Berosus, only Xisuthrus and his wife were carried to the realm of the gods, his companions being informed that the place they were now in was Armenia. "They therefore returned to Babylon, disinterred the sacred writings left at Sippara, founded numerous cities, built temples, and restored Babylon." Berosus also records that pilgrims journeyed to the Gordyan Mountains in Armenia even in his day, and sought fragments of the ark's wreckage to use as amulets against witchcraft.

Little need here be said of the biblical narrative; it is too well known to require telling. What is not generally known, however, is that there are two Jewish renderings of the Deluge story,—the Elohist and the Jehovistic. These are substantially the same, differing only in the length of the flood's duration and certain legal distinctions between clean and unclean animals. The analogies between the Babylonian and Jewish traditions, it will be observed, are very striking, so striking, indeed, that there can be no doubt but that the two were one and the same before the time when Abraham went up out of Chaldea into the land of Palestine. "The conclusion is almost irresistible," says Goldziher, "that the Hebrews borrowed this whole story of the Deluge from the Babylonian original, even in its detail and mode of expression." A discussion of this assertion lies not within the scope of this article. But, whatever the truth, we must admit that the Hebrew narrative lies before us in a purer and more dignified form than the Babylonian. The Jews, in their account, emphasize a moral purpose behind the memorable event, namely, the cleansing of the earth from a corrupt generation of men, and its preparation for a new and better race. Moreover, if the Jews derived their story of the Deluge from the Babylonians, we must credit them with expurgating it of its polytheism, with which the original was burdened.

It is a fact of no little significance that the oldest nation of antiquity should leave us no distinct record of a deluge. The Egyptians, in all their speculations on the cosmogony, make only one distant allusion to the destruction of the human race. Ra, the Creator, becomes so chagrined at the insolence of man that he resolves to exterminate him. He decrees a massacre, the blood of which flows up to Heliopolis, the home of the gods. Ra is so affected by the heinousness of the deed that he repents, and swears nevermore to destroy mankind. There is also reference to an Egyptian legend of the Deluge in Plato's "Timaeus" in which the gods are said to have cleansed and purified the earth by a great flood of water, from which only a few shepherds escaped by climbing to the summit of a high mountain.

There is little about the Flood in Indian mythology. Accounts occur in the "Satapatha Brahmins," in the "Mahabharata," and in the "Bhagavata," but not in the "Rig Veda." The oldest of these accounts is thought to be the legend of Manu, which is thus translated by Max Muller:-

"One morning water for washing was brought to Maiu, and when he had washed himself, a fish remained in his hands. And it addressed these words to him:- 'Protect me, and I will save thee.'

'From what wilt thou save me?' 'A deluge will sweep all creatures away; it is from that I will save thee.' 'How shall I protect thee?' The fish replied: 'While we are small, we run great dangers, for fish swallow fish. Keep me at first in a vase; when I become too large for it, dig a basin to put me into. When I have grown still more, throw me into the ocean; then I shall be preserved from destruction.' Soon it grew a large fish. It said to Manu: "The very year I shall have reached my full growth, the Deluge will happen. Then build a vessel and worship me. When the waters arise, enter the vessel, and I will save thee.'

"After keeping him thus, Manu carried the fish to the sea. In the year indicated, Manu built a vessel and worshipped the fish. And when the Deluge came, he entered the vessel. Then the fish came swimming up to him, and Manu fastened the cable of the ship to the horn of the fish, by which means the latter made it pass over the mountains of the North. The fish said: 'I have saved thee; fasten the vessel to a tree that the water may not sweep it away while thou art in the mountain; and in proportion as the waters decrease, thou shalt descent.' Manu descended with the waters, and this is what is called the Descent of Manu on the mountains of the North. The Deluge had carried away all creatures, and Manu remained alone."

Manu, after the waters had subsided, offered up sacrifice, and obtained thereby a daughter, who supernaturally became the mother of all mankind. Indian scholars, such as Wilson and Burnouf, maintain that this legend of Manu must have been imported from Semitic sources; as the fish feature of the story is foreign to Indian mythology, but was common to that of the Semitic peoples.

The Chinese also have a tradition of a terrible inundation which destroyed their wicked ancestors. In their book "Li-Ki" the Deluge is thus described:-

"And now the pillars of heaven were broken, the earth shook to its very foundation; the sun, and the stars changed their motions, the earth fell to pieces, and the waters inclosed within its bosom burst forth with violence, and overflowed. Man having rebelled against heaven, the system of the universe was totally disordered, and the grand harmony of nature destroyed. All these evils arose from man's despising the supreme power of the universe. He fixed his looks upon terrestrial objects and loved them to excess, until gradually he became transformed into the objects which he loved, and celestial reason entirely abandoned him."

Note that many legends claim that the waters of the Deluge came from within the earth.

In what sublime language does the Chinese sage explain the reason for the flood! Does anything in all the literature and accounts of the Deluge excel it? We answer, unhesitatingly, No. It is possible, however, as Francois Lenormant points out, that the Chinese story refers to such destructive floods as are of historical date, and not to the great cataclysm described in Genesis. What supports this latter view is the fact that there is little in common between the Semitic and the Chinese legends, and that very wide-spread and destructive inundations are known to have occurred in China. In the Chinese Encyclopaedia is an interesting description of East Tartary, which Dr. Tylor in his "Early History of Mankind" quotes at length. The region is described as intersected by mountains and valleys, yet entirely destitute of lakes and rivers. "Nevertheless, there are found in the sand, very far from sea, oyster shells and the shields of crabs. The tradition of the Mongols who inhabit the country is that it has been said from time immemorial that in remote antiquity the waters of the Deluge flooded the district, and when they

retired, the places where they had been made their appearance covered with land." We shall learn further on in this article of other tribes who point to marine remains as proofs of the truth of their Deluge tradition.

Like the Babylonians and the Jews, the Greeks had more than one story of the Deluge. "Plutarch enumerates no fewer than five, and Plato makes his Egyptian priest describe the Greek deluge as oft repeated and numerous." But whether these are but modifications of one original tradition, or really remembrances of several distinct inundations, has long been a matter of uncertainty. The most complete and fascinating of these Greek legends is that of Deucalion. Zeus, the greatest of the national deities, unable to endure any longer the wickedness and insolence of men, resolved to destroy them by a great flood. Warned by his father, Prometheus, of the impending destruction, Deucalion constructed an ark, and took refuge therein with his wife Pyrrha. When the Flood came, the ark floated safely above the waters, and on the ninth day stranded on Mount Parnassus in Thessaly. After the waters had subsided, Deucalion and his wife went to the sanctuary of Themis, and asked the oracle how they might repeople the world. The goddess replied that they must throw behind them the bones of their grandmother. This strange answer perplexed the lonely couple for a considerable time, but finally it dawned upon them that their grandmother was the Earth, the bones of whom were the rocks. So picking up stones, they did as was commanded by the goddess; those which Deucalion threw became men, and those which Pyrrha threw became women. Lucian, in his work "De Dea Syria," relates the legend of Deucalion, which he seems to have obtained from the Asiatic nations, among whom he was born.

"The present race of mankind [wrote Lucian] is different from that which first existed; for those of the antediluvian world were all destroyed. The present world is peopled from the sons of Deucalion, having increased to so great a number from one person. In respect to the former brood, they were men of violence, and lawless in their dealings; they regarded not oaths, nor observed the rites of hospitality, nor showed mercy to those who sued for it. On this account they were doomed to destruction, and for this purpose there was a mighty eruption of waters from the earth, attended with heavy showers from above, so that the rivers swelled and the sea overflowed, till the whole earth was covered with a flood, and all flesh drowned. Deucalion alone was preserved to people the world. This mercy was shown him on account of his justice and piety. His preservation was affected in this manner: He put all his family, both his sons and their wives, into a vast ark which he had provided, and then he went into it himself. At the same time, animals of every species—boars, horses, lions, serpents,—whatever lived upon the face of the earth—followed him by pairs; all of which he received into the ark, and experienced no evil from them, by the immediate influence of the Deity."

When the waters had almost subsided, Deucalion, according to Plutarch, sent forth a dove, which soon returned to him; a second time he sent it forth, and it returned with its feet tinged with mud, thus intimating to him the abatement of the flood. The tradition of the Deluge is not indigenous to the Greeks; if it were, Homer and Hesiod would in all probability have embodied it in their poems. That the Greeks imported it from other peoples is now generally conceded. Some mythologists maintain that it came from Semitic sources; others that it was borrowed from the Hindoos.

Turning now to early Britain, we find that our barbaric ancestors had a fairly complete tradition of the Deluge. Ed. Davies, in his "Mythology and Rites of British Druids," records very fully the Celtic traditions.

"The Druids [he says] represented the Deluge under the figure of a lake, called Llyn Llion, the waters of which burst forth, and covered the face of the whole earth. Hence, they regarded the lake as a just symbol of the Deluge. But the Deluge itself was viewed, not merely as an instrument of punishment to destroy the wicked inhabitants of the globe, but also as a divine illustration, which washed away the bane of corruption and purified the earth for the reception of the 'just ones,' or of the deified patriarch and his family. Consequently, it was deemed peculiarly sacred, and communicated its distinguishing character to those lakes and bays, by which it was locally represented."

The Deluge itself is graphically described as follows:-

"The proHgacy of mankind had provoked the great supreme to send a pestilential wind upon the earth,—a fierce poison descended, and every blast was death. Then the Patriarch, distinguished for his integrity, was shut up, together with his select company, in the enclosure with the strong door. Presently a tempest of fire arose; it spilt the earth asunder to the great deep. The lake Llion then burst its bounds. The waves of the sea lifted themselves on high round the borders of Britain. The rain poured down from heaven, and the waters covered the earth, but that water was intended to purify the polluted world, to render it fit for the renewal of life, and to wash away the contagion and evil of its former inhabitants into the chasms of the Abyss. The flood which swept away the patriarch's contemporaries raised his vessel on high, bore it safely upon the summit of the waters, and proved to him and to his associates to be the water of life and of renovation."

One Celtic legend states that a male and a female of every kind of animal were preserved, and that the cause of the lake Llion's belching forth its destructive waters was a beaver, which a yoke of oxen managed to pull out, so that the lake burst no more. Another legend has it that Dwyvach and Dwyran alone escaped in a naked boat (i. e. a boat without sails), and that these two afterwards repeopled the world. The Druids, according to Mr. Davies, also had a vague idea that some great power protected the world from a repetition of the Deluge.

Leaving now the Old World and its ancient peoples, we come to America. Here mythologists are confronted with considerable difficulty. Missionary effort long preceded any attempt to study in a scientific way the Indians and their legends. The result is that the Red man's ideas are so fused with those of the white man's that it is almost impossible to separate them. Nevertheless, the researches of Schoolcraft and Catlin have done much to bring to light the original myths of that almost extinct race, which hunted and fought in the wilderness of America long before Columbus visited its shores. Stories of the Deluge were very numerous throughout the two Americas, but most of them bear the stamp of Christian influence. "Among the one hundred and twenty different tribes which I have visited in North, South, and Central America," wrote Mr. Catlin, "not a tribe exists that has not related to me distinct or vague traditions of such a calamity, in which one, or three, or eight persons were saved above the waters on the top of a high mountain." Of all the American traditions, the Mexican is considered the least open to the charge of non-originahty. According to Mexican cosmogony, there were four ages, in the last of which—the age of water—men are said to have been turned into fishes. From this fate only one man and one woman were spared,—Tezpi and his wife Hochiquetzal. These two, with their children, took refuge in a ship, taking with them many animals, and every sort of grain. Then in a mighty tempest, the Deluge overwhelmed the earth, but the ship sailed safely over the agitated waters. When the flood began to subside, the ship stranded on Mount Cohuacan, and Tezpi, feeling his boat run aground, sent forth a vulture to ascertain the state of the earth. The vulture, finding carcasses

of animals on the mountain, did not return. "Then Tezpi sent forth a humming bird, which returned with some leaves in its beak. Thereupon Tezpi and his family left their boat and took up their residence on the mount. " The analogies between this legend and some of the Old World traditions of the Deluge are very striking, and have led to considerable speculation on the part of scholars concerning the probable historical connection between America and Asia. Some ethnologists consider the similarity between the mythologies of the Old and the New World as very convincing evidence that the Indian races of America were cradled in the heart of Asia.

The Peruvian story of the Deluge was obtained by the Bishop of Cuzco, in 1570 A. D. , from the lips of elderly priests, who got their information from painted records in the Temple of the Sun near Cuzco. The story bears little or no resemblance to the other American traditions, much less to those of Chaldea and Israel. Previous to the Deluge, the Inca priests explained, man inhabited the earth, but a great cataclysm destroyed all human beings except a man and a woman, who found refuge in a box. In such frail craft they floated hundreds of miles from Cuzco, until they came to an unknown land, where they disembarked. "Here they made clay images of all races, attired them in their natural dress, and then animated them. " These manufactured people buried themselves in the earth, and emerged in various parts of the world, some coming out of fountains, some from trees, and some finding their way out through caves. Thus does the Peruvian explain the diversity of the races on the earth to-day

From the tropical regions of Mexico and Peru and their civilizations, we leap to the frozen North. Here, even here, the stunted Eskimo has preserved a fairly definite story of the Deluge, and passes it down from generation to generation. The Moravian missionary Cranz says that

"The first missionaries among the Greenlanders found a tolerably distinct tradition of the Deluge, of which almost all heathen nations still know something, namely, that the earth was once tilted over, and all men were drowned, but some became fire spirits. The only man who remained alive smote afterwards with his stick upon the ground, and thence came out a woman with whom he peopled the earth again. They tell, moreover, that far up in the country where men could never have dwelt, there are found all sorts of remains of fishes, and even the bones of whales on high mountains, from which they make it clear that the earth was once flooded. "

Such stories should be connected with whale bones and the like found high and dry and far inland.

The North American Indians relate numerous stories of the Deluge, most of which are embellished with the wildest imagination. The Red man, evidently, was not content with sober history; he desired something marvelous and full of intrepidity. And so his legends of the Deluge tell of the exploits of some great hero, then of the land being bathed in a terrible flood, from which the hero escapes to create a new world, and people it with a new race. One of these legends relates the adventures of Manabozo, a renowned chief. Manabozo, it is said, killed the prince of some monstrous serpents, and had to flee for his life from the subject serpents. In spite of his fleetness the serpents gained upon him, and threatened to overtake him. In desperation, Manabozo leaped to the top of a mountain, but when he turned and looked back, lo, the earth was covered with a vast expanse of water which was rapidly rising. He climbed a lofty pine, but to his dismay he found his already high position endangered by the rising waters. Addressing the tree, he cried, "Grandfather, stretch thyself. " The tree obeyed, but the water rose higher and higher. Again he bade the tree to stretch itself,

but it could stretch no more. Up, up the waters rose, as if determined to drag him from his height, but when they reached his chin, they could rise no higher. Looking about him, Manabozo spied a loon, and commanded it to dive and bring up earth, with which he might create a new world. The loon did so, but rose to the surface a corpse. A muskrat then approached him, and thus he spoke to it: "Dive for earth, and if you succeed you may hereafter live on land or water as you please." The muskrat dived, but shared the same fate as the loon. It fulfilled its mission, however, for in its forepaws was clutched a little earth. With this Manabozo created a new world, and placed thereupon new animals and plants. Another Indian legend tells how an ambitious hare undertook to slay the sun, and the fatal consequences which ensued. The hare threw a puff-ball at the sun as it appeared above the horizon, splitting it into a thousand fragments. These fragments, falling on the earth, caused a great conflagration. Forests, lodges, wigwams, and animals were all consumed, and the hare alone was left to gradually suffer for its folly. First his limbs were burned off, then his body was scorched to ashes, and lastly his head was enveloped by relentless flame. Under this torture, the hare's eyes bulged to an enormous size, and finally burst, flooding the earth with oceans of tears and extinguishing the world-wide conflagration.

There is a Guatemala tradition of the Deluge sufficiently unlike the biblical account to remove from it any suspicion of missionary influence. According to this legend, the earth was once inhabited only by animals, but as the brute creation lacked intelligence and was therefore incapable of worshiping, the gods resolved to make creatures in their own image who would be able to worship them. They first fashioned men in clay, but the experiment was a failure, for these creatures could not move their heads nor understand anything. Destroying these with a deluge, the gods made a man of wood and a woman of resin, but the race resulting from this pair were little better than the first brood, and were therefore consumed in a rain of burning resin. A third attempt resulted excellently, for out of white and yellow maize the gods produced four perfect men, and gave unto them four wives of great beauty, three of whom became the mothers of the Quiche's, the fourth not bringing forth any children. Unfortunately, the perfection of these parents of mankind was not hereditary, but, like the Adam of Hebrew mythology, they gave birth to a sinful race of men and women who fondly embraced corruption, and worshiped the Golden Calf and "plated Mars" rather than the great Supreme.

Humboldt, in his travels through the wooded wilderness of the Orinoco, discovered among the Indian tribes which he visited unmistakable traces of Deluge traditions. Among the Tamanacs he even found a tradition which sounds like a faint echo from ancient Greece. They say that the present race of man is descended from a man and a woman who escaped from a great deluge by climbing a high mountain. When the waters subsided, they cast behind them over their heads the fruits of the Mauritia palm-tree, the seeds of which turned into men and women who repeopled the world. Nor was the belief in a deluge confined to the Tamanacs alone, for among the Maypures of the great cataracts, among the Indians of the Rio Erevato, and amongst almost all the tribes of the upper Orinoco, Humboldt was told stories of the Flood, many of which, he thinks, are but remembrances of local inundations, which at times have devastated the tropical regions of South America.

The Maoris of New Zealand had a remarkable legend of the Deluge, remarkable because of its close resemblance to the account contained in Genesis. According to this intelligent race of savages, men had become very numerous on the earth and were involved in perpetual strife. A wave of skepticism had, moreover, swept over mankind, so that the worship of Tane and the other gods was neglected. Indeed, men openly denied that the deities had done what tradition had credited

them with doing, and, instead of revering the prophets, Parawhenua-me and Tupa-nui-a-uta, they abused and scoffed at them. Parawhenua and his brother prophet endured this ill-treatment for a considerable time, but, finding all exhortation and all patience unavailing, they resolved upon radical means to cleanse the earth of its corruption. Building themselves a raft of light timber trees, they called upon the gods to so flood the earth as to convince men of the power of Tane. Their prayer was heard and granted. For five days and five nights the rain descended in torrents, but only the two prophets and a few others, including a woman, escaped the death-engulfing waters. The story goes on to relate the adventures these few privileged souls had on the bosom of the flood, how they anxiously looked for and interpreted the signs in the heavens for its abatement, and with what joy they beheld the reappearance of land and the presence of a rainbow in the sky, which was to them a sign of safety. The other Australasian legends of the Deluge are simple and childish in their make-up, and probably refer to local floods. The natives of the Society Islands tell how a fisherman excited the wrath of Ruahata, god of the sea, by waking him when he was asleep among the corals, and how in his fit of anger Ruahata caused the ocean to leave its bounds and to deluge the earth. Yet strangely enough, he spared the fisherman and his wife from destruction, but only **in** inflict on them the task of repeopleing the world.

There are many other legends of the Deluge, but of comparatively little importance. The Norse and other Aryan peoples all relate stories of the Flood, but so mixed up are these **in** their cosmogonies that it would be burdensome to the reader to give them here. It will be seen from the traditions already related that the belief in a deluge is almost universal among mankind, being found **in** the remotest parts of the earth and even among races so low in their intelligence as to be only able to count on their fingers. Yet it is a singular anomaly that the Negroes of Africa know nothing of a deluge, and that the Egyptians, the most ancient of all peoples, only make a few doubtful references to it. If there was a deluge, we may well ask why no records of it are left on the monuments of Egypt, and why the Negro race has not preserved its memory. The fact is of no little importance that these two great African races—the Egyptians and the Negroes—have lost, or else never had, the story of the Deluge which has clung so persistently to the folk-lore of other peoples.

In addition to the remembrance of the Flood in their traditions, many nations commemorate the event in their religious rites. According to Bryant, the ship Isis, in the Egyptian mysteries, was an emblem of the Ark, and the same writer points out, in detail, religious observances in other countries in which the Ark was treated with reverence, and Noah and his family (under different names, of course) almost worshiped. Further, coins and medals have been found in Greece and other countries of the ancient world, notably Phrygia, which bear imprinted on them pictorial allusions to the Ark and the circumstances attending the Deluge. On one coin, minted in the reign of Philip the Elder, is found the name NOE inscribed "on a floating chest or ark, within which a man and a woman are seen seated, and to which a bird on the wing is represented as bearing a branch."

Now, what is the conclusion naturally forced upon us by the universality of these Deluge traditions, and especially by their remarkable similarity to each other? Christian writers, approaching the subject with preconceived ideas and anxious to prove the truth of biblical records, unhesitatingly answer that the conclusion is inevitable that there was a deluge. Other writers, desirous of destroying the authenticity of the Bible, eager to prove its fallibility, maintain that these traditions of a great deluge are nothing more than myths, that the biblical story itself is a myth, just as much a myth as the story of the tortoise found **in** the mythologies of most races. Both these schools of writers are biased in their point of view, and both are unscientific in their attitude towards the problem.

They set out to prove a theory rather than to elicit the facts; their judgments bear the stamp of personal bias, and so we must accept them with reservation. In our consideration of this question we must be willing to face the facts, no matter to what conclusion they may lead us.

Some of these Deluge traditions, such as the Polynesian, Brazilian, some of the North American Indian, and possibly the Chinese, undoubtedly refer to local phenomena. This is the opinion of that eminent philosophic traveler, Humboldt; and also of Max Muller, the well-known mythologist and scholar. In his "Contributions to the Science of Mythology," the latter says: "There are certain mythological ideas, such as the Deluge, by which their very recurrence among many and widely separated nations shows that they did not arise from some isolated historical fact, as even Huxley seemed to imagine, but that they express physical phenomena which occur and recur every year, and all over the globe." We cannot look into many of these traditions without admitting that Muller's explanation of their existence is probably the true one, but yet it is utterly inadequate to account for them all. The striking similarity of most of these legends demands another theory. We cannot put them all down to coincidence. It is extremely unlikely, though not impossible, that two nations separated by a vast body of water and not knowing of each other's existence, and differing, moreover, in their customs and modes of thought, should invent the same story or narrate a similar event in the same way. How, then, are we to explain the analogies between the Mexican and the Hebrew stories of the Deluge, how are we to account for the common features in many of these traditions, namely, the providential escape of from two to eight persons in an ark or upon a high mountain, the sending out of birds to ascertain the state of the earth, and the preservation of pairs of every kind of animals? And when we further note that the birds sent out to the earth correspond to each other in the various legends, and that there are even agreements in the length of the flood's duration, not to mention the correspondences which philologists have traced in the names given to Noah and his family, etc., we must needs find a theory for these traditions other than that they merely describe local and repeated phenomena. The nature-myth theory of Dr. Tylor clears up much of the difficulty; it may even account exclusively for some of the legends. But even it will not satisfactorily or fully answer the question: How comes it that so many traditions of a deluge, all more or less alike, are found among the most diverse and widely separated races? The only theory left us is that of historical connection. And this is probably the best solution of the problem yet offered. Of all the traditions of the Deluge we can only say positively of a few that they are indigenous in the countries in which they were found. We have seen that the Indian and Greek traditions betray signs of Semitic influence, that the American Indian legends bear the stamp of Christian teaching, or else refer only to local floods.

That there has been a process of borrowing going on is irrefutable; but from whom, we may well ask, did the Mexicans or the Maoris borrow their traditions,—traditions which startle us by their analogies to the Semitic narratives? The great probability is that they never borrowed them at all, but that they have preserved them from time immemorial. Taking everything into account, the unbiased student of comparative mythology and philology is forced to admit that the present great divisions of humanity probably radiated from a common center. If this be so, then it is not altogether inconceivable that before the separation of tribes from the original home took place some great mishap—such as an exceedingly destructive inundation—occurred to the human race which so indelibly impressed itself upon the human mind as never to be erased by centuries or vicissitude. And I may here remark that the memory of this great event would be kept fresh by every minor flood which subsequently took place; for every time the overflow of a river devastated the lands of a tribe, the story of the great overflow would be revived and

thus perpetuated from generation to generation. That these traditions of the Deluge are mostly modifications of one original story, a story which must have been impressed upon the human mind before the dispersion of the human family took place, is the conclusion of many scholars of no mean repute, and of scholars not noted for their devotion to orthodoxy. Francois Lenormant, in a lengthy review of Deluge myths in the Contemporary Review for November, 1879, concludes his article thus:-

"But as the case now stands, we do not hesitate to declare that, far from being a myth, the Biblical Deluge is a real and historical fact, having, to say the least, left its impress on the ancestors of three races—Aryan, or Indo-European, Semitic, or Syrio-Arabian, Chamitic, or Kushite—that is to say on the three great civilized races of the ancient world, those which constitute the higher humanity—before the ancestors of those races had as yet separated, and in the part of Asia together inhabited. "

It is not within the scope of this article to discuss the scientific aspects of the Deluge controversy. Suffice it to say that science does not deny the possibility of a great cataclysm having occurred in Asia, either by a submergence of the land or the overflow of rivers; but it does deny that an inundation such as described in Genesis could have enveloped the whole earth or covered high mountains. A discussion of the geological evidence for and against the Deluge is, I repeat, not within the scope of the present article. We are not here concerned with the testimony of science; we have only to do with the testimony of man. An examination, brief and incomplete though it has been, into the traditions, folk-lore, and religious rites of various peoples has revealed the highly interesting fact that the story of the Deluge is not confined to the chronicles of a single race, but is found among every great division of humanity except the Negroes. Thus does man almost universally testify in his traditions and religions to the outpourings of divine wrath upon the wickedness of his ancestors,—to the almost entire destruction of the race by a terrible deluge.

ELG 001 LEGENDARY ISLANDS OF THE NORTH ATLANTIC

Hopkins, Albert A.; Scientific American Monthly, 4:362-363, October 1921; and 4:14-18, July 1921.

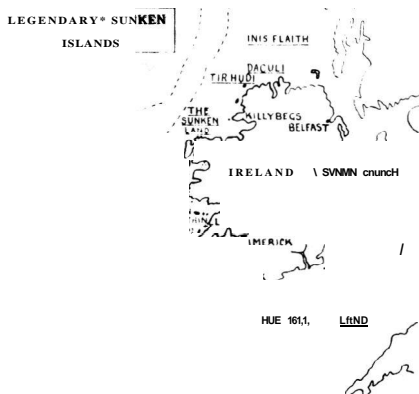
The legend of Atlantis appears frequently in the Series E and M sourcebooks. For the geologist, Atlantis is not the only sunken land, as the following article demonstrates.

"Atlantis" or "Atlantica" was described by Plato as lying just beyond the "Pillars of Hercules" (Straits of Gibraltar). This legendary island, or fragment of continent which sank into the ocean, is inextricably wound up with folk-lore and the whole subject presents a very fascinating side of mythical geography. The present article without endorsing any particular set of views attempt to show certain interesting side lights on this and other mythical islands of the North Atlantic.

After the Renaissance with its renewal of interest in Platonic studies many attempts were made to rationalize the myth of Atlantis and even as late as the 17th and 18th centuries the credibility of the whole legend was seriously debated and sometimes admitted even by such men as Montaigne, Buffon and Voltaire.

A most valuable paper on this subject appeared in the little known Proceedings of the Royal Irish Academy, Vol. XXX, Section C, No. 8, written by T. J. Westropp, M. A., which contains matter of such general interest, for instance, the suggestion that Columbus was affected by these mystic isles and the repeated errors which survived until the middle of the last century, that the writer has condensed this long and scholarly paper, with its minute references, to a few thousand words. These islands are also called "les îles fantastiques."

The Irish Sea-beliefs. The early inhabitants of Ireland, keenly intelligent,



Legendary islands in the vicinity of Ireland

poetical, and with an unusual appreciation for natural beauty, stood on the western coasts face to face with phenomena of mystery and might. It is not wonderful that the great strength roaring beneath their cliff-forts and on the sandhills of their settlements deeply impressed them. Older races had bowed in awe before tamer seas; the Egyptian had feared the "great green one"; the Hebrew had seen God's path in those great waters, and had heard their hymns of praise or cries of deep anguish, when trouble was on the sea and it uttered its voice and raised its hands on high; the early Greeks had evolved from its waves and whirlpools the forms of the Sirens, Charybdis, and Scylla, with her barking waves; the tutor of Nero foretold the loosening of its bonds and the discovery of an unknown continent; while even in the deserts, far from its shores, the Arabian prophet pictured "black night on the deep, which wave on wave doth cover, cloud upon wave, gloom upon gloom." Much more so the Irish, on the outskirts of the known world, felt the wonder that we cannot shelter ourselves from, even by knowledge of natural laws; and their scholars were not unacquainted with what the Scriptures and the classics had to tell.

The coast-dwellers saw the mirage or the cloud-bank brooding on the water: to them it was a floating island,³ possibly to be disenchanted. They saw the foam spring high out to sea, and strange reflections below the waves; it was a magic land that lay there, and the gold-roofed towers and domes glinted deep under the waters, nay, it rose over the waters once in seven years, as men could attest. The ships of the Danaan and Sidh (demons and gods) sailed visible to all, reality and no mirage to the older tribes. The current suddenly foamed in a long tideway, or twisted and writhed; and to the onlookers it was clear that some vast monster swam or turned beneath it; while those lost at sea or in the surf, trying to land, were devoured (thought the survivors) by monsters. The Irish, of course, had no monopoly of such views. Even at the end of the sixteenth century Hakluyt contradicted those who said that the currents "bee swallowed by and cast up againe by the breathing of Demogorgon." The Irish went farther; they regarded the waves as sentient prophetic beings, for, in oldest Irish writers, "the great waves of Erin"—Rudhraigh, Clíodhna, and Tuath—raised their deep voices to foretell disaster and crime, and the wave of Malbay mourned for the death of Keane of Ross, so late in the reign of George II.

In the center of all this weird mystery the pagan Irish placed their heaven, the "Land of Youth," the "Land of the Living," with so firm a belief that, even when they adopted a faith in whose paradise "there was no more sea," they brought their belief along with them.⁴ Devout Christian writers rendered "Tír Tairngiri" as the "Land of Promise" and the "Kingdom of Heaven" in notes on the Epistles to the Corinthians and the Hebrews; the blending was complete and lasting; "Magh Mell of many flowers" was the "Land of Truth," the "Land of the Promise of the Blessed," "whose truth was sung without falsehood." This, however, was equally the "Land of Fair Women," fitter for Islam than for "the Faith"; to this Isle, Connla, King Conn's son, was lured by the woman of the fairy mound. The island was not alone in the deep; "thrice fifty isles" as large as, or "twice and thrice" larger than, Erin, "were counted"; many of these figure in the Voyages of Brendan and elsewhere. The classics were brought into unison with this belief, as the Psalms had been; and we hear of the Hesperides to the west of Aran, "where the sun goes to his couch." The kindred races in Britain doubtless contributed their quota.

Early Sea-tales. The early Gael loved sea-tales. How many of these were lost in the wreck of Irish literature we may never know; some may even yet be recovered, but no less than five have reached us, so we can form a good idea of the Irish belief about the outer sea. Plato's description of Atlantis is closely similar and may have become known through some Greek-reading cleric. The same seems true of Lucian's "True History." The affinities to the sagas of

Ulysses, Aeneas, and Sindbad of the sea are striking. The legends very probably date from the ninth century to the end of the eleventh, the earliest manuscript of "Maelduin" being just before 1100, while one of "Brendan" is alleged to be of the ninth century. St. Brendan's Navigatio had widespread influence on Italian thought, and are among the ancestors of the great Florentine epic. The lesser stories had little influence; but how far the Navigatio of Brendan reacted on Dante and the fifteenth century explorers can hardly be estimated.

Space will not permit of including a resume of all the Irish root sea-tales, so we will pass on to the greatest sea-tale of Brendan, 5 which is called the "Navigatio." It exists in various stages and is possibly a ninth-century sermon elaborated up to its present form by the eleventh century. It was known in some form to the Arabian geographers in Spain about 1150. It spread beyond Ireland among the Normans, being translated for King Henry Beauclere and his wife; and the Anglo-Norman Conquest spread it more and more. It passed to the Portuguese, and probably stimulated the designs of Prince Henry the Navigator, and a little later those of Columbus. It was a source of Dante's great poem. What truth lies behind it is difficult to guess. 'Matter-of-fact writers have treated it as a genuine log-book; but poets have more truly seen in it a revelation of great symbolic beauty. It is more than probable that St. Brendan (like SS. Columba, Colman, and Flannan) was actually a daring voyager; and that in some lost "Life," his actual visits to various islands were told. We are less concerned with the actual facts than with the stories that so impressed the world. Columbus was in touch not only with the Portuguese, but with Bristol, the merchants of which sent seven expeditions to search for "Brasil" before the fifteenth century ended. He also had at least one Irish sailor with him on the great voyage of 1492; from any or all of these he may have heard the Brendan legends.

See MLG-001 for further surmises about St. Brendan's supposed voyages.

The Most Famous of the Phantom Islands. "Brasil" or "Brazil" takes a prominent place in the early maps of Italy, Spain, France, and even England and Germany. Its name is obscure; some say it is from the Irish "Bres," noble, or, as Nansen says, "fortunate." It was clearly brought about in pre-historic times by mirage and fog-bank. The setting sun and the place of the dead helped its religious significance; it became the "Isle of the Living," the "Isle of Truth," the "Isle of Joy," the "Isle of Fair Women," the "Isle of Apples," "an Eden, away, far away." Christianity, trustee to dead Paganism, made it the "Land of Promise." Then the belief materialized before commerce, and it became (as Sir David Wilson writes**) "an imaginary island of Brasil that flitted about the maps of the fourteenth and fifteenth centuries with ever-varying site and proportion, till it vanished. It was not a reef or a shoal, but a mist or mirage 'sprung from the sea without root'; but it held its place on the charts from 1320 to 1865, and was said to have been seen at close quarters in 1791."

Columbus and the Mythic Islands. This is no place for any elaborate study of the most interesting question relating to the mythic islands, namely, how far the belief in them affected the discovery of Columbus. A few notes must suffice. It will be remembered that Christopher Columbus based his great enterprise on three errors—the extension of Asia so far eastward as to reach within a comparatively short distance from the west of Europe; the inaccurately small circumference of the world; and the existence of large islands in mid-ocean. The maps of two centuries and the traditions known to him bore out the last item. The Spaniards believed so firmly in the Isle of the Seven Cities that they actually inserted a clause in the Treaty of Evora with Portugal, reserving "the islands which had not been found," and the people of the Canaries also petitioned to be allowed to annex it. Columbus, as his son Ferdinand records, knew of Seneca's

future continent and of Aristotle's Antilia. This almost certainly implies knowledge of the Atlantis legend. He gathered all he could learn of these and of St. Borondon's Isle, and the Seven Cities. He had heard of Antonio Leone (or Leme) reaching an island 100 leagues west from Madeira, of two floating islands, more to the south-west, mentioned by Juventius Fortunatus, and of a Madeiran asking for a caravel in which to seek for Antilia. Peter Velasques, a pilot, told Columbus at La Rabida how, in the time of Prince Henry, his Master (born 1394, died 1460), James de Fine, going from Fayal to Cape Clear, in Ireland, about 1450, got under shelter of an unknown isle to the west of Ireland. Peter Velasques, of Galicia, confirmed this of his own knowledge, and Columbus had a letter of Vincent Dea, a Portuguese, telling how he had seen an island beyond Madeira. The great explorer went northward, heard what the Bristol merchants (indefatigable seekers for Brasil) had to tell, and in February, 1477, sailed 100 leagues beyond Thile (Ireland). There, if the passage be not an interpolation, he may well have seen manuscripts such as exist, dated fifty to seventy years before his visit, telling, in matter-of-fact words, of Greenland, Helluland, Markland, and Vinland (the last "stretching toward Africa"), with wide channels between, and manuals are often more convincing than folios. He was in touch with Galway, the center of Irish lore of Hy Brasil, for he included among his sailors in 1492 William Irez, of Galway, in Ireland. He cites religious legends for accounts of the wonderful birds and plants of the ocean islands. He fully expected to meet such islands on his way to Cipango, Cathay, and the Indies; what he did not expect was to be walled off from Asia by a vast continent. The belief in the islands must have been of the first importance to encourage him and his men on their daring voyage when they burst into the silent sea.

Atlantis and Other Lost Lands. Though it has not been demonstrated that Plato's descriptions of Atlantis were known to the Irish, the probability is considerable. Seneca's works were actually in the Library of the great Hiberno-Italian school of Bobbio, while St. Gall had another famous early library to which scholars (and perhaps monastic redactors of the Brendan Saga) would most likely have resorted. This is no place to go deeply into the question as to whether Plato actually heard a genuine legend of Egyptian priests from the time of Solon, and if so how an alleged historic event of B. C. 9600 could have been handed down even to the Egyptians of the early dynasties 5,000 years later. The point which concerns us is the unmistakable likeness of the mythical Atlantis to the islands seen by the Irish writings concerning Bran, Maelduin, and Brendan. As in "Bran," where the sea-god Mananann is father of Mongan by an Irish princess, so, in Atlantis, his equivalent, Poseidon, has ten sons by mortal mothers. Atlantis has a marvellous fort with rings of three fosses and two walls of bronze, tin, and aurichalchon or red copper; so, in the legends of Maelduin and Hui Corra, is the ring-fort with brazen rampart, palisade, and bridge over a wet fosse. Atlantis was walled all round, so are the Irish legendary isles. In both we hear of wonderful temples and altars, fountains of hot and cold water, well-planted groves and a wonderful race course; the parallel is close indeed, whatever degree of connexion there may be between them. Atlantis is said to have lain outside the Straits of Gibraltar, to have been as large as Asia (Minor) and Lybia combined, and, after overrunning all the Mediterranean shores to Tyrrhenia and Egypt, its armies were checked by Athens; eventually it sank in a day and a night during an earthquake, and was entirely submerged by the sea, leaving dangerous shoals. The resemblances between Lucian's "True History" and the Irish tales are most striking.

The Atlantis legend reached the Arabian geographers along with the Irish and Norse tales. The Arabs were believed to have crossed the Atlantic; and the Observatory of Sagres, under the influence of Prince Henry the Navigator, collected all records of voyages, with the result that Madeira was rediscovered

(or discovered if the alleged Bristol settler be mythic), and the voyages commenced which at last doubled the Cape of Good Hope. The nearest neighbors of the early Irish were not without similar beliefs. The Britons believed in the elusive Isle of Avalon. The Welsh, too, had their great lost land sunk by a drunken, careless prince. There was also the lost land of Lyonesse, or Lennoys, of which the Scilly Isles are said to be the last remnants. Florence of Worcester (died 1118) tells of its flourishing condition and how it sank, like Atlantis, beneath the waves. It, like Avalon, was never placed on the early maps, and there is no evidence that it affected either the Irish or Iberian beliefs, though it secured a place in English literature through Tennyson and Swinburne. Scotland, too, had her "Flaith Inis," which was surrounded by clouds and tempests, with an island, "Caereccennfinn," between Scotland and Ireland, where the Irish of Ulster placed their "Tir Hudi." The Bretons had their submerged city of Is; the French and Portuguese told of the mythic Isles of Maida, Asmaida, or Asmanda and Isle of Verte, Ilha Verde, suggesting the Inis Glas of other legends. The Spaniards had their tale of Antilia and the Isle of the Seven Cities of the Gothic kings and bishops who fled from the Moors to them in 714, while Ireland, England, France, Portugal, and Spain agreed in believing that outside human trade, rarely within the limits of sight, lay Brasil and St. Brendan's Isle, the Fortunate Islands, the Isle of Birds, and the Isle of Sheep. The reader who is interested in Atlantis and who wishes to carry on further reading can consult the best authority, Pierre Termier. "Atlantis" in the Annual Report of the Smithsonian Institution for 1915, pp. 219-234. This translation is more accessible than the original paper which appeared in the Bull. de l'Inst. Oceanogr. No. 256, Monaco, 1913. At the request of the American Geographical Society this brilliant paper was reviewed in their journal, the Geographical Review, for January, 1917, by Dr. Rudolph Schuller, formerly of Para, and Prof. Charles Schuchert of Yale.

In the early eighties Ignatius Donnelly, a prominent thinker of the time, presented what will probably remain the best brief for the existence of this remnant of a continent called "Atlantis," in a book which is a marvel of logic, called "Atlantis: The Antediluvian World." This work set out to demonstrate several distinct and novel propositions. These are:

1. That there once existed in the Atlantic Ocean, opposite the mouth of the Mediterranean Sea, a large island, which was the remnant of an Atlantic continent, and known to the ancient world as Atlantis.
2. That the description of this island given by Plato is not, as has been long supposed, fable, but veritable history.
3. That Atlantis was the region where man first rose from a state of barbarism to civilization.
4. That it became, in the course of ages, a populous and mighty nation, from whose overflows the shores of the Gulf of Mexico, the Mississippi River, the Amazon, the Pacific coast of South America, the Mediterranean, the west coast of Europe and Africa, the Baltic, the Black Sea, and the Caspian were populated by civilized nations.
5. That it was the true antediluvian world; the Garden of Eden; the Gardens of the Hesperides; the Elysian Fields; the Gardens of Alcinous; the Mesomphalos; the Olympos; the Asgard of the traditions of the ancient nations; representing a universal memory of a great land, where early mankind dwelt for ages in peace and happiness.
6. That the gods and goddesses of the ancient Greeks, the Phoenicians, the Hindoos, and the Scandinavians were simply the kings, queens, and heroes of Atlantis; and the acts attributed to them in mythology are a confused recollection of real historical events.
7. That the mythology of Egypt and Peru represented the original religion of Atlantis, which was sun-worship.

8. That the oldest colony formed by the Atlanteans was probably in Egypt, whose civilization was a reproduction of that of the Atlantic island.

9. That the implements of the "Bronze Age" of Europe were derived from Atlantis. The Atlanteans were also the first manufacturers of iron.

10. That the Phoenician alphabet, parent of all the European alphabets, was derived from an Atlantis alphabet, which was also conveyed from Atlantis to the Mayas of Central America.

11. That Atlantis was the original seat of the Aryan or Indo-European family of nations, as well as the Semitic peoples, and possibly also of the Turanian races.

12. That Atlantis perished in a terrible convulsion of nature, in which the whole island sunk into the ocean, with nearly all its inhabitants.

13. That a few persons escaped in ships and on rafts, and carried to the nations east and west the tidings of the appalling catastrophe, which has survived to our own time in the Flood and Deluge legends of the different nations of the old and new worlds.

The Mythical Islands in Early Maps. Interest in the islands of the Atlantic hardly existed before the twelfth century among the map-makers. The "Life of St. Brendan" had been spreading over the Continent for over a century before it began to affect the maps. Apart from his works there is no certain trace in the other maps of the imaginary isles till Dulcert in 1325 to 1339. These charts founded on experience and, as their name implied, showing the route from port to port, avoided the conventional, and strove to draw information from every source. The island corresponding to Brasil is also found in the Venetian map of 1367 and the far superior Catalan map of 1373, which marks a large circular island "Insula Berzil," in the same place, west from the Shannon, as also St. Brendan's Isle and Mam to the south of Brasil. It will be remembered that the compass was apparently known in the thirteenth century to Roger Bacon, and later to Dante's tutor, Brunetto Latini; but the latter says that sailors would not have it on board, regarding it as "an infernal spirit." It only became popular about 1360, so that its use, the making of the early maps, and the "appearance" of Brasil, all seem to be contemporaneous. The I. de Brasil is shown among the Azores, and a nameless isle, the mythic "Brazil," to the west of Ireland in the Venetian map of Andrea Bianco in 1436. One of the finest maps before Columbus, that of Frau Mauro, in 1450, identified Brasil with the Fortunate Islands. Mauro was known as the "*Cosmographus incomparabilis*"; he was a Venetian friar, and a medal was struck in his honor. To the fifteenth century belongs a Catalan compass chart; it marks "Ylle de brazill" a double island and (twice as far from Irlanda as it) another Brazill to the west of it, Ille Verde, and still further to the north "Fixland," apparently Iceland. In the very year when Columbus first reached the islands of America, Martin Behaim (or Bohemus) of Nurnburg made his famous globe. It shows Brasil and St. Brendan's Isle, the latter half-way between Ireland and Japan, in 1492.

If interest in geography was getting so keen and bearing fruit in the Portuguese expeditions down the coast of Africa, and the Spanish ones to the West Indies, it might be expected that it grew keener than ever after the great turning-point in history of that year, when "Columbus gave a New World to Castile and Leon." Two names passed from mythic and half-mythic islands; "Brazil" and "Antilia" attached themselves to actual countries; but though Antilia passed from the map of the Old World, Brasil still held its own off the Irish coast, though its name had been transferred to the land of the giant river and forests, greater and more beautiful than bard or monk had ever fancied.

England, having so narrowly lost her chance of being patron to Columbus, was now taking her place among the world-explorers. In August, 1497, the minister of the Duke of Milan wrote to his master from England to say that Cabot

had found two large and fertile islands, San Juan and Prima Vista, and had found the "Seven Cities," 400 leagues from England. Eleven months later the Spanish Ambassador in London wrote to Ferdinand and Isabella, telling of Cabot's discoveries and second expedition, and telling how "the men of Bristol have, for the last seven years" (since 1492), "sent every year, two, three, or four caravels to search for the Isle of Brasil and the Seven Cities." Next year, 1499, the real Brazil was discovered.

The increasing traffic with America in the sixteenth century might have been supposed to have swept all the mythic tales into the "Never-Never Land," whence they had come; but this was not the case; and we must see how for some three centuries the islands held their own, while, perhaps, the earliest and latest of the group, Brasil and Buss, were found on maps till past the middle of the nineteenth century. In 1598 and 1599, Hakluyt gives Iceland, "with Frisland, half way between it and Estotiland. Not content with this, he collects a circumstantial report of the finding of Buss, the latest mythic island of the North Atlantic, and which (with Brasil, the earliest to find place on the maps) held its own down to very recent times. The most interesting section of the map-history of Brasil and its sister isles ends with the sixteenth century. A few instances are given in the original paper to show the continuity of the belief. Estotiland, St. Brandon's Isle, and Antilia, do not appear in any map after 1700, as far as Mr. Westropp knows; Brasil, Buss and Maida survived. Brasil is in Jeffrey's American Atlas in the year 1776 in longitude 17°35' west, and lying west from Cape Clear. St. Brendan's Isle is also given. Buss was only eliminated in 1850. Brasil was finally removed from the charts so late as 1865. John Purdy's general chart of the Atlantic (corrected in 1830) says that the Brasil Rock was high and was fixed at 51°30' west. In a chart of currents in A. Findlay's edition of "Purdy," and in the "Mémorial, Description, and Explanation of the North Atlantic Ocean" we read "Brasil Rock, lat. 51°10' long. 16°" M. Bellin in 1742 states that this rock is "marked in lat. 51°10' long. 19°30' Paris." Its existence has been doubted by Messrs. Verdun and Border. "It was, however, seen in the year 1791 by the company and master of an English merchant ship, the commander of which favoured the world with a description of it, stating that it is really a high rock, or islet, and by which he passed so near that he could have 'cast a biscuit on shore.' We suspect that if it exists it is more to the westward." Findlay's doubts increased, and he eliminated Brasil finally in 1865, after it had held its place for over 550 years on the maps. Local histories assert that the Channel Isles were connected with France up to 709, and that when St. Lo visited Jersey on inspection in 565 he could cross into it by a plank.

Conclusions as to the Legendary Islands. Mr. Westropp sums up his conclusions, leaving to scientific men the questions of subsidence and the formation of the ocean-beds, which some have put back to the dateless Miocene:

1. The outer isles, Brasil, Brendan's and Ailbe's, are purely mythical, or, at best, based on mirage and fog-bank. This may be modified, should it be proved that the Porcupine Bank (which so closely corresponds in position with Brasil) has been above water even in an early human period.

2. The traditional islands along the coast, which are represented by actual reefs, were very probably actual islands down to a late period. The case of Mutton Island, split into three parts between 799 and 803, shows that the deep hollows now found between the fragments belong to merely 1100 years of denudation.

3. Of folk-lore, the power of fire to disenchant and fix firmly any phantom island is a cardinal article of belief; so is the appearance of these lands at intervals of seven years.

4. Some islands, though possibly none in these coasts, may have been upheaved and sunk by some volcanic outburst. Very possibly some such event

originated the tradition of the vast continent sunk in the waves of which Plato told.

It is probable that red dye woods used in the Middle Ages were connected with Brasil, the mythical and that the familiar existence of "Brasil" as a geographical name led to its bestowal upon the vast region of South America, which was found to supply dye-woods kindred to those which the name denoted.

To the Editor of the Scientific American Monthly:

I have been very much interested in reading articles under the above title on the "Legendary Islands of the North Atlantic" by Albert A. Hopkins, in the July issue of the Scientific American Monthly.

It puts me in mind of a lecture which I heard some years ago by Dr. Ronald Strath in Seattle, who had spent some time in Yucatan studying the prehistoric monuments and inscriptions of the Mayas in the jungle. According to Dr. Strath, whose lecture made a vivid impression on me at the time, these inscriptions, which are very voluminous and were then by no means completely translated, gave a complete and very detailed description of the destruction of Atlantis, by a planetoid grazing the surface of the earth, and raising such a heavy cloud that the earth was dark for eighteen months. As I remember it, the date of the catastrophe was also set by astronomical data at about 13,000 years B. C. ; and that the earth comes into imminent danger of another similar catastrophe about every 52,000 years.

The inscriptions, if his interpretation of them is correct, give a marvelously complete history of events of the people of Atlantis over a period of several thousand years, together with an account of their social and religious institutions, etc. I was particularly impressed with them by reason of accounts given of struggles over many social problems, such as woman's suffrage, which are supposed to be distinctly modern in character. I also remember an account of a system of suffrage which was worked out, whereby both men and women could vote; but the weight of vote was varied with different individuals of different ages and attainments. Thus an elderly man of experience in affairs exerted more influence than a young man just old enough to vote. There were also many laws, which for simple yet effective justice in a fairly complicated society, are certainly not equaled in the present day. Their code was evidently the basis for the code of Hammurabi of Babylon, who lived at the time of the scriptural Abraham, and who compiled the earliest hitherto known historic code of laws.

According to Dr. Strath, who I believe had also been in India and Asia as a British Army surgeon, and had made a study of archaeology in those places, the civilization of Atlantis was the parent of the old world civilizations; and the old world nations were founded as colonies of the people of Atlantis. He showed how the architectures of Egypt, Babylon, Ancient Greece, etc., are plainly developments of the architecture of Mayapan, which was the architecture of Atlantis. He showed a photograph of a sphinx in Mayapan very similar to that of Egypt; and told of an account in the inscriptions of Mayapan of the building of the Egyptian sphinx by an exiled queen of Atlantis in memory of her assassinated brother.

He also showed a connection between the Atlantian language and the parents of the civilized languages of the present day, with intent to prove that the Atlantian language, as shown in the inscriptions of Mayapan was the parent language of the modern languages.

I am a layman in the subject at land, and not in a position to judge of the reliability of Dr. Strath's work. If reliable, it should set at rest forever any question of the authenticity of the Atlantian legends. The inscriptions, illustrated in the lecture, are certainly far too voluminous to have been the result of any hoax. I have also seen other pictures of the same monuments and inscrip-

tions elsewhere. An engineer of my acquaintance has made a number of pleasure trips to Mexico and Central America, and has also obtained a collection of very fine photographs of some of the monuments and inscriptions of Central America. While he obtained them simply as curiosities, and seems to have little idea of their significance, I have no doubt that he could be influenced to publish them, if they would be of interest, without explanation or attempt at interpretation.

Dr. Strath also referred me to a book by Le Plongeon (initials of author and title of book forgotten). I borrowed it but was unable to read this work at the time, though I glanced through it; and made out that in general it seemed to confirm Dr. Strath's conclusions very closely. I have never been able to obtain the book since.

An interesting feature in connection with the account of the destruction of Atlantis by a planetoid, is the fact which I read in a book on geology when a boy, that the geological formation of the diamond fields of Brazil and of Africa can only be accounted for by such a catastrophe as is described in the account of the destruction of Atlantis. Any physicist knows that diamonds are only formed under the intense heat and pressure that such a catastrophe would entail.

It is also interesting to theorise on what would happen to the earth in the event of such a catastrophe and compare that with legendary accounts; the intense heat of collision, though the blow was only a glancing one, would vaporize vast quantities of the water of the Atlantic, which with, clouds of fine ash would be carried in the atmosphere all over the surface of the earth and literally darken the sun. The whole earth would quake and would continue quaking until the mal-adjustments in the crust brought about by the strain had again become adjusted. Volcanic activity would everywhere tend to increase. On the cooling of the evaporated ocean waters, rains of violence never before or since equaled would cover the earth. There could easily be wide changes brought about in the elevation of lands and the outline of coastal shores. Many things that have puzzled geologists could easily be explained by such a catastrophe. The Sahara desert has never been satisfactorily explained, I believe. It would not take a very large asteroid to accomplish such a result; indeed the collision of one of the larger of them would probably destroy all animal life on the earth, so great would be its disturbances. But it occurs to me that some of our astronomers could furnish information bearing on the matter, by telling us whether there is any known asteroid whose path came close enough to the earth at that time for a collision, and whether there is anything in the legend of a 52,000 year periodicity of danger of such a collision with the earth.

If I recall my astronomy correctly, this is approximately the period of the spinning of the earth's axis with relation to the plane of the earth's orbit. It is well known that some of the asteroids have orbits of such eccentricity as to pass close to the earth's orbit. It might well be that one of them would cross the earth's orbit at the time when the earth happened to be close enough to draw it into collision only once in 52,000 years. Certain of the ancients had a wonderful knowledge of astronomy; it is not impossible that they could compute orbits.

I am also inclined to wonder whether the Sargasso Sea—that refuse heap known to mariners of the flotsam of the Atlantic, brought by wind and current from all parts of the ocean, is not responsible for some of the legends of floating islands in the Atlantic. It certainly has an appearance which might easily give the impression of a floating island.

However, this is all speculation. The great pity of it all is that knowledge has reached the point where it takes all of a man's life to obtain a complete knowledge of one subject, let alone sufficient of others to be able to correlate them and obtain really sound conclusions. Scientists used to trace consanguinity of races by lingual similarities, until so many cases of the imposition of the language of one race upon a totally alien race came to light that language

was seen to be a totally inadequate basis for their work. But similar conclusions are being drawn from equally inadequate bases in nearly all research work nowadays. The natural sciences, it is true, are beginning to draw together. But the process is but beginning. And we still have the geologist drawing conclusions which a little knowledge of astronomy or of physics shows to be unsound, the biologist working blindly at a problem which a knowledge of chemistry would immediately solve, the Freudian psychologist drawing conclusions utterly at variance with anthropology and history. Not only are research men unacquainted with the work in other sciences, but so many of them are utterly lacking in that quality of sound judgment brought about by contact with human affairs, which is called common sense. So many of them are prone to go mooning about their specialties in utter oblivion to all that is going on in the great and wonderful world around them, and become unbalanced to the point where they are incapable of sound judgment even in their own specialties, however wonderful their detailed knowledge of those specialties may be. I know, for I have several scholars among my immediate friends and relatives and am only too well acquainted at first hand with the narrowness and jealousies of some of them, and how directly it affects their work. My father repeatedly has taken part in faculty meetings of one of our institutions, wherein the curricula of the students are determined. Such meetings become scrambles in which each professor is intent only on seeing how much of his particular specialty he can jam into the curriculum. Nor is this particular institution any marked exception. I have heard of the same thing in one of the foremost universities of the country. [We have seen it in such a university.—The Editor.]

1 A book entitled "Legendary Islands of the Atlantic," by William H. Babcock will be published shortly by the American Geographical Society as a monograph in their Research Series. It will contain interesting maps and will be a scholarly contribution to an interesting subject. See also "The Island of the Seven Cities" by the same author. Geog. Review, Feb., 1919.

2 So also on the opposite shore of the Old World the Chinese had legends of "Isles of the Blessed," 700 miles eastward in the Yellow Sea; places of everlasting spring, gladness and beauty. Their secret was revealed to the Emperor Tshe Huan Ti about B. C. 219. Youths went out to find the Isle, and saw it in roseate light on the horizon, but storms drove them away. Similar stories are told in Japan of the happy isle of Oraison, far out to sea.—Nansen, "In Northern Mists."

3 "Voyages," Vol. II, p. 9.

4 Those who held that Eden lay eastward were met (both by those who held that the earth was spherical and those who held it was flat) by the argument that Asia reached around to opposite Europe, so that the farthest east was near the west shores of Ireland.

5 The literature on this subject is large. Consult Rev. S. Baring Gould, "Curious Myths of the Middle Ages."

6 "The Lost Atlantis," 1892.

7 Plato, "Timaeus" VI.; and "Critias III, VHI, XV. See also Dr. Robert F. Sharff's paper, "Proceedings of the Royal Irish Academy, Vol. XXIV, Section B., Part IB.

8 "Voyages," 1599, Vol. II., p. 33.

SECTION EM: MAGNETIC DATA

The discipline of geomagnetism has helped add continental drift, sea-floor spreading, magnetic reversals, and other concepts to our overall picture of the earth's past. But to borrow the title of an article from Nature of the early 1970s, "Could Paleomagnetism Be Wrong?" As entries in this section accumulate, it will become obvious that the answer to this question might be "yes".

- EMA Magnetic anomalies. Strong, permanent magnetic anomalies of unexplained origin. These may be local or global in extent.
- EMR Magnetic reversals. The supposed reversals of the earth's magnetic poles. Since magnetic reversals are now an accepted part of geophysical dogma, only contradictory data will be presented here, along with correlations of reversals with unexpected phenomena.

MAGNETIC DATA

Permanent anomalies of the earth's magnetic field exist on both large and small scales. The global asymmetries may tell us something about the origin of our planet (and perhaps our moon) and its internal constitution. Small-scale anomalies are rather common and usually betray local geological features, such as iron deposits. Only the exceptional and more intriguing of the local anomalies are described in this subsection. Geomagnetic transients of unusual character are filed in section GM in the STRANGE PHENOMENA series of sourcebooks.

EMA-001 THE MAGNETIC POLES OF THE EARTH AND THE BIRTH OF THE MOON

Lee, Oliver J. and Longfellow, D. W. ; Science, 72:89, July 25, 1930 and 72:424-425, October 24, 1930.

Geophysicists recognize many structural asymmetries of the earth, such as the existence of continents of land and an elliptical figure of an equatorial sea-level section. The inequality of the two axes of this ellipse is of the order of one kilometer, the major axis terminating in central Africa and in Hawaii, the minor axis in Sumatra and the Andes.

A remarkable asymmetry exists in the longitude of the earth's magnetic poles, which are at present in 96° west and 155° east longitudes. They are, therefore, only 109° apart, and their longitudes mark out roughly the average boundaries of the Pacific Ocean, the vast basin of which has many "deeps" and is enclosed by a giant circlet of extinct and active volcanoes. If this basin is the birthplace of the moon, it does not seem unreasonable to expect that enough of the heavier, deep-lying magnetic elements in the earth may have been torn along, placenta-wise, on that natal occasion to actually fix the magnetic poles of the earth in these regions. Perhaps it would be better to say that when the lunar material departed, a shift in the distribution of magnetic materials within the remaining mass took place toward the Pacific basin.

While it seems difficult to believe that the readjustment of the earth to approximately spherical form after such an enormous loss could leave anything fixed, other asymmetric vestiges of diastrophic changes in the earth during its long history have survived so that the one discussed here may not be ruled out a priori.

Attention may have been called to this bit of circumstantial evidence that the moon was born of the earth, but I have not found any mention of it in a casual perusal of several recent books on geology and geophysics. (Oliver J. Lee)

Dr. Oliver Justin Lee's article on "The Magnetic Poles of the Earth and the Birth of the Moon" in Science of July 25 interests me greatly.

A number of years ago I was impressed with the same fact, namely, that the magnetic poles are not on the axis of the earth, which would seem to be the logical place for them, nor are they even antipodal to each other. When I found that the shortest distance between them was across the center of the Pacific I immediately began to wonder if the removal of the moon mass from the area which is now the Pacific was responsible for this peculiar fact.

In 1926 I had a number of mimeographed copies made of a short article on "The Origin of the Moon" which consisted of about 14 ordinary letter size sheets of typewritten material.

By 1927 I became impressed more with the earthly effects and had a twenty-six page booklet printed giving a large number of facts which seemed to me to support the theory that the removal of a large mass of crustal material, from

what is now part of the Pacific Ocean, caused the shifting of the axis of rotation of the earth, caused the magnetic poles to become closer to each other on the Pacific side of the globe and created the major outlines of the continents. The title of this booklet is "The Formation of the Continents and Oceans as We Know Them."

In the September, 1928, issue of the Pan-American Geologist an article of mine on "Symmetric Disposition of Tertiary Mountain Systems" was published. This calls attention to a very remarkable symmetry which is created when, on a globe, the magnetic poles, together with underlying continents, are placed back in their assumed original positions.

In the March, 1929, issue of the same journal another article of mine on "Continental Drifting in Northwestern Europe" was published. This article was not confined to a statement of the one bit of contributory evidence which the title indicates, but covers briefly some of the major features of my theory and the evidence supporting it.

In the May, 1930, issue of the same journal an article which I contributed on "Bilateral Symmetry of Earth's Largest Continental Block," with an illustration, described a symmetry of Europe, Asia and Africa around a great circle passing through the south magnetic pole, which I attribute to the removal of a large mass from part of the Pacific, which mass may now be our moon.

Before the Geological Section of the American Association for the Advancement of Science, at their Des Moines meeting last winter, I read a paper, with lantern illustrations, setting forth my theory and the facts on which it was built as well as a small part of the supporting evidence.

I have seen no other mention of this peculiar relationship that seems to exist between the magnetic elements of the earth and the major features of the earth.

Some of the conclusions which the evidence in the case has forced me to are almost revolutionary.

My theory, in a very peculiar manner, seems to fit in, to a certain degree, with Wegener's theory of continental drift of the Americas, so I submitted my theory to W. A. J. M. van Waterschoot van der Gracht, who recently conducted a symposium on the theory of continental drift. Of my theory and the facts which I advance in support of it he recently wrote me as follows:

These curious magnetic facts must have some explanation, and they may be very important for further speculation as to the internal constitution of the earth, and also for the changes in its facial expression. . . . I think that your work brings some very interesting new facts and arguments into the discussion of this most involved problem. . . . Your discussion of the magnetic situation is very interesting and certainly deserves further work and thought.

(D. W. Longfellow)

Of course, the idea that the moon was torn from the earth (where now resides the Pacific Ocean) is an old one. Osmond Fisher and George H. Darwin supported the concept in the late 1800s.

EMR-001 COULD PALAEOMAGNETISM BE WRONG?

Anonymous: Nature, 227:776, August 22, 1970.

Modern geophysicists have become just as wedded to the continental drift hypotheses as their predecessors were to the dogma of permanent ocean basins. Perhaps neither theory is right. A great deal of modern geology is based upon paleomagnetism.

It is now clear that palaeomagnetic data provide the crucial evidence in favour of continental drift, sea floor spreading and plate tectonics, and the other ingredients of what has been called the "new global tectonics" in which the oceans are not only the youngest part of the Earth but are still being formed. The idea of global mobility has become the central dogma of Earth science. Naturally enough, like most dogmas it has attracted uncritical adherents.

Palaeomagnetic data are not the only evidence for global mobility, but they have the advantage of being quantitative. Although palaeontological, geological and palaeoclimatological data are mostly consistent with continental movements defined by palaeomagnetic poles, they usually have the status of supporting evidence simply because they are more difficult to quantify. Thus the doctrine of continental drift is consistent with what is known of the Earth's climatic zone pattern, but the broadness of the climatic zones means that it has been difficult to make precise use of climatological criteria. It has therefore always been an open question as to what would happen if anyone were to compare the results of palaeomagnetism more quantitatively with evidence from other sources.

This crunch has now come, although in a small way. The story is this. Continental movements are determined palaeomagnetically on the assumption that throughout the period covered by the rock record, the Earth's magnetic field has been axially dipolar. Needless to say, this is a reasonable assumption not internally inconsistent, but equally not susceptible to direct proof. Yet without such proof, palaeomagnetism falls to the ground. But Stehli (J. Geophys. Res., 75, 3325; 1970) now claims, on the basis of an analysis of palaeontological data, that for the Permian the axial hypothesis is not valid. Taken in isolation, his evidence is convincing because it is quantitative. His analysis is based on the observation that certain brachiopods are temperature dependent. The lower the temperature at any given place, the fewer brachiopod families there will be, which means that the diversity of brachiopod families will be a maximum around the equator but will fall off as the latitude increases. That this is the case is shown by the behavior of Recent clams whose family diversity falls off quadratically with increasing latitude. The problem with Permian brachiopods from the northern hemisphere is that family diversity does not vary quadratically with palaeomagnetic latitude but does so when plotted on the present latitude grid. When plotted on the Permian palaeomagnetic latitude grid the Permian diversity bears no particular relationship to latitude, just as when the Recent clam diversity is plotted on the Permian palaeolatitude grid there is, as would be expected, no simple relationship. In short, the Permian axial field is not consistent with the Permian brachiopod diversity whereas the present latitude grid is. And if this is true for the Permian it could be true for other geological periods. That is why palaeomagnetists cannot afford to ignore Stehli's conclusions.

The first and most obvious question to ask, of course is whether the palaeontological sampling was adequate for clearly the number of brachiopod families detected at a given latitude will be critically dependent on the intensity of sampling. Stehli, at least, is satisfied on this score. In the samples of Recent clams there were sixteen families of "cosmopolitan dominants" which being more or less temperature independent, were found at more than 70 per cent of the

EMR-002 MAGNETIC REVERSALS

sampling stations. These were used to test the sampling efficiency. On the assumption that perfect sampling would reveal all sixteen families, the number actually discovered at any given sampling station gives a crude indication of the total proportion of families sampled. The cosmopolitan dominants themselves were not included in the diversity calculations simply because they were not temperature dependent and thus of no use in testing latitude dependence.

The second question which can legitimately be asked is whether the palaeomagnetic data from North America and Eurasia are sufficient to define the true geomagnetic field for the Permian. The answer is that they are, as far as it is possible to tell, because in North American and Eurasian poles agree when the two continents are reconstructed in their pre-continental drift positions determined without reference to palaeomagnetism. This is in itself evidence—but not proof—in favour of the Permian axial dipole field because pole positions are calculated using the axis dipole assumption.

If Stehli's analysis is valid—and it is difficult at present to show that it is not—the only conclusion to be drawn in isolation is that the Permian field was not axial. Palaeomagnetic evidence, on the other hand, cannot prove that it was axial but does offer strong evidence to that effect. Palaeontological and palaeomagnetic evidence are thus in conflict, which means, unless some unifying principle is discovered, that one or the other is wrong.

EMR-002 NO CORRELATIONS IN THE CANARIES

Anonymous; Nature, 227:1002, September 5, 1970.

A thorn in the side of the field of paleomagnetism is "self-reversal"—the tendency of the magnetic field of a rock sample to reverse spontaneously. If this sort of thing happens frequently, the whole fabric of modern plate tectonics and continental drift could be wrong. As the following article demonstrates, lingering doubts remain.

One of the most fascinating unsolved problems in palaeomagnetism is the source of the correlations between magnetic polarity and oxidation state found in rocks from certain sites. The construction of a polarity-time scale for the past 4.5 million years, the deduction from magnetic anomalies at sea that alternating periods of normal and reversed polarity extend backwards in time for many tens of millions of years, the evidence from baked contact rocks and the fact that about fifty per cent of the world's rocks are reversely magnetized, leave no doubt that almost all reversed rocks were produced during periods when the Earth's magnetic field was reversed. This being the case, there should be no correlation whatsoever between the magnetic polarity of rocks and their physical, chemical or mineralogical properties. Indeed, the existence of such correlations would be positive evidence for self-reversal, a phenomenon known to exist but support for which is overwhelmed by the evidence in favour of field reversal.

What, then, can be the explanation for the observed correlations? Reversed Quaternary and Tertiary lava flows from Iceland, reversed Tertiary flows from Japan and reversed Carboniferous flows from Scotland all contain significantly more separate ilmenite than the normal flows from those sites: and statistically, the titanomagnetites in reversed Tertiary flows in Scotland, Iceland and the Columbia Plateau, Oregon, and in reversed dykes in Scotland are more highly oxidized than those in the corresponding normal rocks. The first question which

needs to be asked is, of course, whether these correlations are fortuitous. After all, they represent a negligible proportion of the world's rocks, and many of these particular samples obey the classic tests for field reversal. The reason why so few correlations have been reported is simply that the work involved is long and tedious. Yet in spite of the small number, they share one property which argues against their arising by coincidence—they are all in the same sense. It is always the reversely magnetized rocks which are, on average, more highly oxidized, never the normal ones.

Even so, the significance of the oxidation-polarity correlations will ultimately be firmly established or rejected by statistic; and that is why a new report by Ade-Hall and Watkins (*Geophys. J.*, 19, 351; 1970) is important. For these authors have carried out a petrographic and magnetic analysis of 168 Miocene to Pliocene basalt, ankaramite and phonolite lava flows from the Canary Islands, and find no correlation whatsoever between polarity and oxidation. There is, of course, always the possibility that the correlation really exists but is obscured in some way; but Ade-Hall and Watkins have carefully considered this problem and conclude that it does not arise here. It is possible, for example, that a collection which comprises three different rock types, each of which possesses a different but real polarity-oxidation relationship, might exhibit no overall correlation. A separate analysis for each rock type represented, however, revealed a correlation for none. Then again, it is possible that a correlation could be obscured by experimental limitations. It may, have been, for example, that the x1200 magnification used by Ade-Hall and Watkins in their petrographic analysis was insufficient to resolve fine exsolution of ilmenite in the titanomagnetite grains. This was also ruled out by low temperature Curie point measurements which failed to indicate the presence of any ilmenite at all.

So how does this new non-correlation affect the status of the oxidation-polarity problem in general? The answer is that by itself it makes little difference to the overall situation, for one brick is sufficient neither to build nor to demolish a structure. But it does have two-fold importance. For one thing, it emphasizes together with two other non-correlations, that oxidation polarity relationships are not universal. This in turn serves to emphasize the statistical nature of the whole problem. And second, it stresses that, in this matter, negative results—the absence of correlation—are as significant as positive data. The long-term problem is, of course, that a vast amount of work will be necessary on other rock collections before it can be proved that the correlations observed hitherto are not trivial. But if the case is ultimately proved, it will be a major headache for Earth scientists. For, given the reality of field reversal, it is difficult at present to imagine what physical connexion there could be between the oxidation state of lavas which originate in the upper mantle and the magnetic field which is produced in the Earth's core.

EMR-003 A NEW MAGNETIC REVERSAL AT 12,500 YEARS?

Anonymous; Nature, 234:441, December 24, 1971.

In next Monday's Nature Physical Science (December 27) Morner et al. report their discovery of a reversely magnetized sediment section about 12,500 years old. The section in question is part of an oriented core, 14.5 m long, from Gothenburg, south-west Sweden, which spans the time range 12,600 years to

EMR-004 MAGNETIC REVERSALS

8,600 years before present (from the early Agard Interstadial to the mid-Boreal) —and there is little doubt that this dating is correct. The stratigraphy of southern Scandinavia is well known and a well dated climatic zone system has been determined for this range of time. For the Gothenburg core both climatic and stratigraphic dating agree well.

The core contains thirteen stratigraphic units, only the lowermost (earliest) sample (layer 13) of which is reversely magnetized. The boundary between units 13 and 12 is the boundary between the Agard Interstadial and (above) the Fjaras Stadial and has previously been dated at 12,400 years old. Thus in the view of Morner and his colleagues 12,400 years represents the upper boundary of a reversal event in the archaeological section of the Brunhes normal epoch.

The palaeomagnetic measurements, including magnetic cleaning up to 200 oersteds, show that the remanent magnetizations are stable—but normal for units 1-12 and reversed for unit 13. Morner and his colleagues are thus well supported in their report that reversely magnetized material exists in the late Weichselian. But the contention that this represents a genuine field reversal is much less secure. For one thing no search for self-reversal characteristics is reported; and no confirmation from other sections is yet available. Moreover, although the probability that many short events remain to be discovered is now widely accepted, it is equally clear that the definition of short events is likely to be difficult—partly because a given short event will tend to be recorded less often, partly because such events are hard to distinguish from the spurious effects unavoidable in the Earth sciences, and partly because if self reversal operates at all it is likely to manifest itself exactly in this small scale situation.

The best known, and better documented, short reversed event alleged to lie in the Brunhes is, of course, the so-called Laschamp event; and this is far from being widely accepted as valid. Under these circumstances it may seem a little premature to name the new, apparent event.

An Atlantist might claim that this very recent reversal occurred during the catastrophe that saw the demise of legendary Atlantis.

EMR-004 VARIATIONS IN MAGNETIC INTENSITY AND CLIMATIC CHANGES

Wollin, Goesta, et al; Nature, 232:549-551, August 20, 1971.

The conclusions of this paper should be read in the context of other correlations [EMR-005 and ERM-004] which suggest a cause-and-effect link between magnetic reversals, tektite falls, and biological extinctions.

Correlation between the variations of the Earth's magnetic field, fluctuations in atmospheric radiocarbon activity, and climatic changes during the past 7,000 yr has been discussed extensively in the past. In addition, Harrison has suggested that reversals of the Earth's magnetic field could cause climatic changes. With an associate we have recently been able tentatively to conclude on the basis of studies of deep-sea sediment cores that in the past 470,000 yr the magnetism of the Earth has modulated climate. We have now extended the correlation between variations of the magnetic intensity and evidence of climatic change from deep-sea sediment cores back to 1.2 m.y.

Many investigators have studied remanent magnetism in deep-sea sediment cores. The study was conducted according to the method of Opdyke *et al.* The cores on which the remanent magnetism was measured were sampled at intervals of 2 to 10 cm and dried samples were cut into rough cubes measuring approximately 2 cm. Reversals were detected by finding the inclination of the remanent field of the series of samples with respect to the axis of the core. The samples were partially demagnetized in an alternating field of 150 oersted to remove unstable components.

Core analysis details are omitted here.

We have shown correlations between variations in magnetic intensity and climatic changes. On the basis of evidence reported here and additional evidence we suggest that cause and effect relationship links changes of the Earth's magnetic field and climate. For instance, higher magnetic intensity seems to indicate colder climate. Thus we conclude that magnetism may modulate climate to some degree by the ability of the Earth's magnetic field somehow to provide a shield against solar corpuscular radiation.

EMR-005 GEOMAGNETIC POLARITY CHANGE, VOLCANIC MAXIMA AND FAUNAL EXTINCTION IN THE SOUTH PACIFIC

Kennett, J. P., and Watkins, N. D. ; *Nature*, 227:930-934, August 29, 1970.

Geomagnetic field reversals occurred more than twenty times during the past 4 m.y. and probably more than one hundred times during the Tertiary. The most significant aspect of this discovery is the recognition of important features of the history of geomagnetic polarity in the linear magnetic anomalies of the oceanic crust, and their convincing interpretation in terms of sea-floor spreading.

The geomagnetic polarity history has also been recognized in deep-sea sedimentary cores. In such studies, several microfaunal extinctions and appearances have been recognized as synchronous, and virtually simultaneous with the period of transition between opposite geomagnetic polarities which lasts about 5,000 years. The reasons for these extinctions and appearances are unknown, but they may be the result of climatic change and polarity change being related, or of increased mutation rates during polarity changes, although several authors oppose this possibility.

Heirtzler has recently speculated on a relationship between earthquake activity (and by implication upper mantle activity) and geomagnetic polarity change. He reasons that because there is evidence to show that earthquakes of magnitude 7.5 or greater may cause wobble of the spin axis, it is therefore conceivable that an Earth wobble may be of a magnitude sufficient also to cause reversal of the geomagnetic field. Here we present data pertinent to Heirtzler's speculations, and we expand such speculations to include our preferred explanation of the synchronous geomagnetic polarity changes and faunal extinctions.

We know of no method to detect the time of occurrence and frequency of large earthquakes in the geological past. Stress release is often manifested in volcanic activity, however, so a search may be profitably made for evidence of relationships between volcanic maxima and geomagnetic polarity change.

Volcanism certainly may have more than one cause, and on a global scale must be virtually continuous, so we therefore emphasize our use of the term "volcanic maxima". If relationships exist between polarity change and upper mantle activity they are more likely to be found in oceanic areas, for there the mantle is most mobile and accessible, and (in all probability) more commonly at "threshold", in terms of potential volcanism. Our search therefore examines the character of volcanic activity during polarity change in some deep-sea sedimentary cores.

Analysis techniques are omitted here.

Figs. 1 and 2 clearly show that when geomagnetic polarity changes were taking place, volcanic maxima were also occurring, at least locally. Volcanic fragments are most abundant and consistent in their occurrence close to the Brunhes-Matuyama boundary (0.7 m.y.), near the Matuyama-Gauss boundary (2.4 m.y.), and during at least two periods within the Brunhes epoch (0 to 0.7 m.y.). Other less well defined horizons are related in part to the sediments of the shorter duration events, and the Gauss Gilbert boundary. Volcanism was clearly taking place locally during other periods. It is intriguing that the Brunhes-Matuyama and Matuyama-Gauss polarity changes are remote from evidence of volcanic activity in only one of the fourteen such examples contained in the eight cores shown in Fig. 2. (Figs, not reproduced)

We now briefly examine the relevance of our data to problems of climatic changes and microfaunal extinctions and appearances. If significant widespread increases in volcanism have occurred during restricted intervals of geological time, then climatic changes are very likely, particularly at high latitudes, because volcanic ash, which remains in the atmosphere for prolonged intervals of time and moves poleward at high altitudes, inhibits solar radiation at the surface. In this context it is therefore possibly significant that a distinct world-wide cooling occurred near the Brunhes-Matuyama boundary, and that other climatic coolings may be associated with the Gilsa event and Matuyama-Gauss boundary. Increases in volcanism within the Brunhes epoch as indicated by us in the Southern Oceans occur in New Zealand (personal communication from H. W. Wellman). This coincides with, and may be related to, the much greater climatic fluctuation of the past 0.7 m.y., compared with the preceding million years.

Of eight observed microfaunal extinctions and appearances in the Southern Ocean, six occur either during or very close to geomagnetic polarity changes. We suggest that the climatic changes which can result from volcanic maxima are much more plausibly the cause of such extinctions and appearances than increased radiation at the water surface during any dipole collapse accompanying a polarity change, although other explanations must be considered.

We conclude that our results provide sufficient evidence to justify serious consideration of Heirtzler's speculations of a connexion between geomagnetic polarity change and upper mantle activity, which was also proposed by Hide. Volcanic maxima during polarity changes may be expected to have an influence on climatic conditions, particularly at very high latitudes, and may therefore also be the indirect cause of those microfaunal extinctions which have occurred during geomagnetic polarity changes.

SECTION EO:

ORBITAL AND ASTRONOMICAL EVIDENCE

The earth's climate and the geological forces that have molded its surface and interior are affected by and, in some instances, initiated by, the earth's relation to the rest of the solar system. The position of the earth's axis of rotation, in particular, may have had an important influence upon past glacial activity; the same thing may have been true with respect to the shape and inclination of the planet's orbit around the sun. More controversial is the subject of "polar flipping" where the axis of rotation may have changed 180°, causing widespread catastrophism. Relevant astronomical data are collected in this section, although it is impossible to divorce descriptions of consequent geological effects. This section has a bearing upon the theories of Drayson, Hapgood, and Velikovsky—catastrophists all.

- EOA Astronomical observations. The shape of the earth's orbit and the position of the earth's axis of rotation as related to climatic cycles, Ice Ages, etc.
- EOS Solar, lunar, and planetary effects. Correlations suggesting physical relationships between the positions of the sun, moon, and planets, and the potential perturbations of meteorite impacts on the earth's axis of rotation.

*This subsection not represented in Volume EI.

ORBITAL AND ASTRONOMICAL EVIDENCE

Climate changes and terrestrial catastrophes are ascribed by some to changes in the earth's axis of rotation. Although an effort is made to excise data from theory, it is impossible in the subsection to completely exclude radical and sometimes mistaken interpretations of the data.

EOA-001 THE LAST GLACIAL PERIOD

Anonymous; Nature, 8-301, August 14, 1873.

The following is a hostile book review of Drayson's famous (or infamous) work.

On the Cause, Date, and Duration of the Last Glacial Epoch of Geology, and the Probable Antiquity of Man. With an investigation and description of a new movement of the Earth. By Lieut.-Colonel Drayson, R. A., F. R. A. S. (London: Chapman and Hall, 1873.)

The author of this work allows the existence of the motion of rotation of the earth on its axis and its revolution round the sun. That motion, however, of the axis of the earth, to which is due the precession of the equinoxes, is to him a great stumbling block. He denies the possibility of this motion as generally accepted, and gives us a theory of his own, which is very novel, and the results of which are startling in the extreme.

Lieut.-Colonel Drayson either knows nothing of dynamics or despises the science: the one key he makes use of to unlock the secrets of astronomy is geometry; he does not believe in the existence of a change in the plane of the ecliptic, and apparently is not aware that the attractions of the other planets on the earth must produce periodic changes in the plane of the earth's orbit. In consequence of this he persuades himself that all astronomers teach (and perhaps believe) that while the pole of the earth is describing a circle round the pole of the ecliptic, the obliquity of the ecliptic, which is the angular distance between these poles, is constantly changing. He calls this a geometrical impossibility, and nobody would hesitate to agree with him that it is; but astronomers would at once deny that they either teach or believe anything of the kind. The popular belief is that the pole of the earth describes a circle of radius $23^{\circ} 28'$ round the pole of the ecliptic as a centre, and that the whole circle would be described in something over 25,000 years.

Lieut.-Colonel Drayson tells us that the true motion of the pole of the earth is in a circle whose radius is $29^{\circ} 25' 47''$, and whose centre is at a distance of 6° from the pole of the ecliptic. He attempts to prove this, and, we believe, has succeeded in persuading himself that he has proved it. He does this by showing that this particular circle will satisfy all the necessary conditions, as he puts them, and also (we assume) as he understands them. The author next proceeds to deduce the consequences of this motion. His circle would be described in 31,840 years, so that at intervals of 15,920 years the obliquity of the ecliptic would vary as much as 12° . The consequence of this would be that about 13,700 B. C., Great Britain would have had during the winter an arctic climate, the sun in lat. 54° not being 1° above the horizon at the winter solstice, and during the summer a tropical climate. This is supposed to have been the last glacial epoch, and the author has such confidence in his theory that he promises us glacial epochs every 31,840 years.

The book, as a whole, we look upon as most unsatisfactory. Had the author mastered the principles of dynamics, he probably would not have been led by a mistaken interpretation of movements which he only partly understood, into the fatal error of attempting to solve one of the most abstruse problems in astronomy

EOA-002 ASTRONOMICAL OBSERVATIONS

by mere geometry. The days of such attempts were, we hoped, past forever.

The motion of the earth's axis is well illustrated by the motion of a boy's top when it is spinning with its axis inclined to the vertical. Every one has seen a top while spinning on its own axis, revolve round the vertical with approximately constant speed, while its axis remained inclined to the vertical at an approximately constant angle: but who has seen a top spinning so that its axis revolved with constant speed round a line inclined to the vertical at an angle of 6° , or any other angle? Till Lieut.-Colonel Drayson produces a top which will do this, thereby proving experimentally that such a motion is possible, or till he demonstrates by analysis the possibility of such a motion, we shall feel confident in rejecting his theory of the earth's motion, as the theory of a paradoxer, and in regarding the cause of the last glacial epoch as a secret still unknown.

Drayson's ideas should be compared with modern astronomical theories of the glacial period, such as that of Milankovitch. In several respects, Drayson's case resembles that of Velikovsky.

EOA-002 THE DRAYSONIAN HERESY AND CLIMATIC CHANGES

Jones, Harold S.; Nineteenth Century, 136:159-165, October 1944. Letters by various authors, as indicated; 137,237-240, May 1945.

In an article entitled 'Climate and the Arctic Route' in The Nineteenth Century for July, Brigadier N. M. McLeod accepts the hypothesis advocated by the late Major-General A. W. Drayson, of a 12 degrees variation in the obliquity of the ecliptic in a precessional cycle of roughly 32,000 years, as providing a satisfactory explanation of past climatic changes on the earth. He adds that 'it is up to the official astronomers either to prove definitely that Drayson was wrong, and if so, in what respect, or to acknowledge the truth of his discovery.' The eminence of Brigadier McLeod in his own sphere of work requires that this challenge be accepted, lest readers who do not possess the technical knowledge to judge for themselves of the matters in dispute may be led astray.

Before dealing with Drayson's claims, let me state, for the benefit of non-technical readers, the orthodox view, which Drayson criticised. The plane of the earth's equator intersects the ecliptic, the plane of the orbit of the earth round the sun, in a line whose direction is not fixed, but has a slow retrograde motion, which causes it to make one complete turn in about 26,000 years. This phenomenon, known as the precession of the equinoxes, was discovered by Hipparchus in 125 B. C. It implies that the direction of the plane of the equator or of the ecliptic or of both cannot be exactly constant.

Astronomical observations have shown that neither of them is fixed, though the motion of the equator is much greater than the motion of the ecliptic.

The matter can be looked at in another way by considering the motions of the poles of the two planes. Instead of the motions of the planes themselves. The pole of a plane is the point where a line at right angles to the plane meets the celestial sphere. The axis about which the earth rotates does not maintain a fixed direction in space; the celestial pole has a circular motion around the instantaneous position of the pole of the ecliptic, but the pole of the ecliptic is itself slowly moving. The combined motion of the two poles gives rise to a slow change in the obliquity of the ecliptic, as the angle between the planes of the equator and ecliptic is termed.

Drayson's stumbling block was the conception of a moving centre. This is the more surprising, because it is one of the oldest conceptions in astronomy. Thus, for instance, the moon describes an orbit round the earth, which is itself in motion round the sun. The ancient Greek astronomers represented the movements of the planets in the heavens by motion around a circle, whose centre in turn moved in a circular path round the earth. But Drayson could not accept the statement that the pole of the earth was moving round the pole of the ecliptic as a centre and yet that the pole of the ecliptic was itself in motion. He seems also to have been led astray by statements in popular text-books current in his time, which he interpreted too literally. He made the arbitrary assumption that the pole of the earth must be moving round a fixed centre. The pole of the ecliptic was assumed also to be fixed and to be eccentric to the fixed centre. The motion of the pole of the earth round the fixed centre, on these assumptions, results in a gradual change in the distance of the pole of the earth from the pole of the ecliptic, which is equal to the obliquity of the ecliptic.

By a process of trial and error, Drayson placed his fixed centre at a distance of exactly 6 degrees from the pole of the ecliptic. For this purpose he used determinations of the obliquity of the ecliptic, together with data extracted from the Nautical Almanac. But he placed too much trust in the early measures of the obliquity, which have a very large uncertainty. Let it be noted that Drayson selected results obtained by the 'orthodox' astronomers, whom he so mistrusted, but at the same time conveniently ignored other results which did not fit in with his hypothesis. It is the usual procedure of the paradoxer—to pick and choose anything that fits in with his own theories and to condemn everything that does not. If, for instance, he had accepted the calculations of the latitudes (distances from the ecliptic) of stars, made by various astronomers, he would have seen that these latitudes were slowly changing, proving that the ecliptic and therefore also its pole must be slowly moving.

Drayson termed the motion of the pole of the earth around its assumed fixed centre 'the second rotation of the earth.' He made extravagant claims for his hypothesis. Thus, in the preface to one of his books, * he states that 'the reader of this book . . . will be able to accomplish by calculation, in a few hours, more than the astronomers of the whole world have been able to arrive at by their perpetual observations during the past two hundred years.'

The conception of this 'second rotation of the earth' is purely geometrical. It cannot be supported by dynamical principles. Drayson, indeed, sought for no such justification of his hypothesis. But astronomy is not merely a matter of geometry. The planets and the stars move according to definite dynamical laws, whose formulation was the immortal achievement of Newton. According to Newton's law of universal gravitation, every particle of matter attracts every other particle, with forces depending upon their masses and their distances apart. The working out of the consequences of this law, applied to the solar system, and its confirmation by the accurate representation of the motions of the moon, the planets and comets is the great achievement of celestial mechanics, aptly described by Professor F. R. Moulton as follows:

'At the present time celestial mechanics is entitled to be regarded as the most perfect science and one of the most splendid achievements of the human mind. No other science is based on so many observations extending over so long a time. In no other science is it possible to treat so critically its conclusions, and in no other are theory and experience in so perfect accord. There are thousands of small deviations from conic sections motion in the orbits of the planets, satellites and comets, where theory and the observations exactly agree

* Thirty Thousand Years of the Earth's Past History, 1888.

while the only unexplained irregularities (probably due to unknown forces) are a very few small ones in the motion of the moon and the motion of the perihelion of the orbit of Mercury.* Over and over again theory has outrun practice and indicated the existence of peculiarities of motion which had not yet been derived from observations. Its perfection during the time covered by experience inspires confidence in following it back into the past to a time before observations began, and into the future to a time when perhaps they shall have ceased.'

With such a consistent unity, is it surprising that Drayson's hypothesis, unsupported either by theory or observation, has not been accepted by astronomers? It is not possible to remove one stone without destroying the whole edifice of celestial mechanics. To accept Drayson's views is to reject the work, amongst others, of Newton, of the great geometers and mathematicians of the eighteenth century—Euler, Lagrange and Laplace, of Adams and Leverrier and Newcomb.

The supporters of Drayson's hypothesis have made much of the fact that from Drayson's data it is possible to predict polar distances of the stars that are in reasonably fair accordance with observation. But this is not surprising; it is to be expected. For it is the motions of the equator and ecliptic that give rise, in the main, to the changes in the polar distances of the stars. Any arbitrary hypothesis that will represent these motions with fair accuracy over a period of time will necessarily also represent with fair accuracy the changes in the polar distances of the stars during that period. Two circles which are tangential to one another at a point A and whose radii are not too greatly different will diverge only slowly from one another in the vicinity of the point A. Such a tangential fit to the true motion of the pole of the earth was what Drayson secured by his trial and error method. Thus approximate agreement over a period of 50 or 100 years between observations and the computations from Drayson's hypothesis provides no support for the correctness of the hypothesis. With lapse of time there will be an increasing divergence between the observed positions and the Draysonian computed positions; divergencies in excess of the uncertainties of the observations are, in fact, already appearing.

Some explanation will now be given of the dynamical causes of the movements of the equator and the ecliptic. The movement of the equator and the precessional motion of its pole are caused by the gravitational attractions of the sun and moon on the earth. Because the axis of the earth is inclined to the ecliptic and because the earth is spheroidal in shape (the polar axis being shorter than the equatorial axis) the attractions of the sun and moon are tending to tilt the earth, so as to bring the plane of the equator into the ecliptic. This is what would happen if the earth had no rotation; but the rotation of the earth gives rise to a gyroscopic effect, so that the turning couple on the earth causes the axis of rotation of the earth slowly to describe a cone about the axis of the ecliptic, in a direction opposite to that of the earth's rotation. This can be shown quite simply by well-established dynamical principles and the effect can be illustrated by an ordinary gyrostatis. There is no escape from the conclusion that the centre about which the earth's pole is turning is the pole of the ecliptic. The rate of the precessional rotation can be computed in terms of the mean motions of the sun and moon, the mass of the moon and various constants of the moon's orbit, together with the dynamical flattening of the earth. All the quantities involved can be determined by direct observation except the dynamical flattening, which

* Since this was written, these have been explained. The irregularities in the motion of the moon have been proved to be the result of small variations in the rate of rotation of the earth. The motion of the perihelion of Mercury is exactly accounted for by Einstein's generalised theory of relativity. [A controversial matter today. Compiler]

can, however, be inferred from other astronomical constants. The calculated rate of the precessional motion is in good agreement with the observed value. But inasmuch as the rate of the precessional rotation is one of the most accurately determined of fundamental astronomical constants, astronomers prefer to reverse the procedure and to use the observed rate of precessional motion to give the most accurate determination of the dynamical flattening of the earth.

The movement of the ecliptic has a different cause. Because of the universal nature of gravitation, each planet exerts a gravitational pull on every other planet. These mutual pulls are continually varying as the planets move around their several orbits. The varying mutual attractions cause slow changes in the shape of the orbits, in their planes, and in the orientation of each orbit in its plane. The changes can all be calculated, though the calculations are of great complexity; they can be expressed, for purposes of practical computations, in terms of the time, measured from any arbitrary epoch.

It is found in this way that the obliquity of the ecliptic can be expressed in the form

$$23^{\circ}27'8''.26 - 46''.845T - 0''.0059T^2 + 0''.00181T^3$$

where the time T is expressed in centuries from 1900 so that for the year 2000, for instance, T has the value + 1.0. The only part of this expression derived directly from observation is the value for 1900, corresponding to T=0. The remainder is purely a computational result. It gives a rate of change of the obliquity which is in agreement with observation: this is more than Drayson's hypothesis can do, for Drayson merely adopted the rate of change given by contemporary observations. Incidentally, the above expression shows that the rate of change of the obliquity is not uniform with time; Drayson incorrectly assumed and frequently stated that 'orthodox' astronomy required the rate of change of the obliquity to be uniform.

The representation of the obliquity in the above form is sufficiently accurate for computing the obliquity for many hundreds of years before or after 1900. It cannot be used for the remote past or the remote future. To compute the obliquity at such an epoch it would be necessary to know the shapes and positions of the orbits of all the planets at the epoch in question or to work backwards by numerical integration—a long, tedious and complex process. Laplace was able to prove, however, that the extreme possible variation in the obliquity is not much in excess of 3 degrees, whereas Drayson's hypothesis requires an extreme variation of 12 degrees.

Thus, from accepted dynamical principles, it is possible to account for the motion of the pole of the equator round the pole of the ecliptic and to compute its rate; it is possible also to account for the movement of the plane of the ecliptic and to compute the motion of its pole. The inferred rate of change of the obliquity of the ecliptic is in agreement with observation. How different from Drayson's ad hoc hypothesis, which proves nothing!

Because Drayson's conceptions are in contradiction to dynamical principles, it necessarily followed that in various respects they conflicted with observation. Thus, for instance, they require the rate of precession of the earth's axis to be variable, because the pole of the ecliptic is not, on this hypothesis, at the centre of the motion of the earth's pole. The non-existence of this variation had to be explained. The explanation given by Drayson was simple enough—it was fraud on the part of professional astronomers, and this necessarily implies concerted fraud by astronomers in all countries. To such lengths does blind adherence to a false hypothesis lead! Presumably there was an Astronomers' International Defence League, to bamboozle their governments and so to safeguard their own positions and to enable large staffs to be employed on unnecessary observations when Drayson, sitting at his desk, could in a few hours have done all that was

necessary. As Abraham Lincoln said: 'You can fool all the people some of the time, and some of the people all the time, but you cannot fool all the people all of the time'—and certainly not Major-General Drayson. In a letter to Admiral de Horsey, he wrote—

'Any error as small as 0'. 711 per year might go on accumulating during several years, and then might be adjusted at all the observatories, without the outside public knowing anything about it. . . . Outsiders, unless possessing an observatory, and having the best instruments, chronometers, etc., have no means of discovering the right ascensions of the stars other than accepting that which is given in the Nautical Almanac. A person may know there is an error in the standard measure of time, and yet for calculation he must take the data given in the Nautical Almanac in order to work out details.'

Drayson denied the reality of the proper or intrinsic motions of individual stars and of the reality of the motion of the sun towards a point in the constellation of Hercules. When positions of stars at two different epochs are to be compared, the effects of precession during the interval must be allowed for. Drayson asserted that because of the current false ideas about precession, the reduction from the one epoch to the other was in error and the error was conveniently obscured by calling it proper-motion. Yet by photographing nearby stars on a photographic plate and comparing with another photograph taken a year or so later the proper-motions of the stars can be clearly revealed, entirely independently of any precessional complication. Moreover, by the spectroscope, the actual linear velocities of stars in the line of sight can be measured; if the stars have no proper-motions, they must all be moving either directly towards or directly away from the earth!

These and many other false results from his hypothesis Drayson conveniently side-tracked by frequent references to the 'subterfuges' of astronomers and their 'fudge rules.' He alone was right; the 'orthodox' astronomers, in an unholy league with each other, were all wrong.

Brigadier McLeod in his article collected some evidence to support the conclusion that within the past twenty-five years or so there has been a rise in the temperature of the polar regions. He then brought in Drayson's hypothesis to account for this. But the suggested explanation is a non sequitur. The rate of change of the obliquity at the present time according to Drayson's hypothesis is necessarily in close accordance with the rate of change according to 'orthodox' astronomy. In twenty-five years the obliquity changes by less than 12". Brigadier McLeod cannot seriously believe that so minute a change in the obliquity can cause the winter temperature at Spitsbergen, for instance, to be 16 degrees higher in 1931-35 than it was in 1911-20!

The cause of cold and warm periods in the past history of the earth still remains to be established. It is certainly not to be found in Drayson's hypothesis. The most likely cause seems to me to be the one suggested by Sir George Simpson, that the sun's output of heat is liable to secular change. Many stars are known to vary in their radiation, some regularly, others irregularly; some rapidly, others slowly; some by a small amount, others by a large amount. There is much evidence that the sun's radiation is liable to small irregular variations; but absorption and scattering in the earth's atmosphere, changing from day to day and even from hour to hour, make definite conclusions impossible at the present time. Accurate observations of the brightness of the planets may serve in the future to provide a check. But neither for the sun nor for any star of apparently constant brightness is it possible to say whether or not there have been slow secular variations in brightness in the course of thousands of years. What is surprising is that for many stars the balance between the rate of generation of energy inside the star and the rate of radiation from its surface has been so exact during the limited period over which reliable observations

have extended. There may well be a slow secular variation in the rate of generation of energy, accompanied by a corresponding variation in the rate of radiation. And, moreover, the variations in the sun's radiation needed to account for the past warm and cold periods on the earth are very much smaller than the variations which have been observed in many other stars.

The letters in response to Jones' article follow.

Sir,—May I, of your courtesy, offer a few words to strip off the 'orthodox' camouflage and leave the real issue once more exposed to view. Drayson's shortcomings are in no wise to the point. We contend solely for the path of the pole of the heavens.

The Astronomer Royal has admitted Drayson's polar trace as representing the sum of instantaneous tangential arcs centred on the ecliptic pole E, supposedly moving. Professor Stratton has also admitted that we Draysonians have the centre of curvature of the polar trace. So much for Drayson's geometrical discovery.

The resultant path of the pole of the heavens P is therefore clearly established by two independent methods, pure geometry and dynamical computation, as a curve indistinguishable from the arc of a circle centred on Drayson's centre C, with radius $29^{\circ} 25' 47''$.

What known force is there at work to vary the curvature of this arc or cause its centre to deviate from C? Within limits of accurate observation there is nothing to suggest any material change throughout the 32,000 years of an entire precessional cycle. Now, since the supposedly moving ecliptic pole is located from epoch to epoch on the radius CP, to square with the above movement of P in its precessional circle, E, if moving as alleged, must make a revolution around C in a curve which bears no relationship whatever to, nor may be in any way reconciled with, the accepted maximum long-term deviation of the ecliptic pole, $1^{\circ} 21'$ 'in an immense period of ages.'

This being so, until these two irreconcilable movements of the ecliptic can be explained dynamically, Drayson's Climatic Theory holds good.

The words cited by the Astronomer Royal from p.4 of 'Equator and Ecliptic,' (foot), implied solely that Draysonians had not yet worked out quantitatively the effect of the displacement of the zenith of each several observatory, from which zenith right ascensions and declinations of stars are derived. Qualitatively these effects are easily demonstrable to any unprejudiced mind, and it is only a matter of sufficient time and thought to define them by exact measurement for each epoch at each observatory, as Drayson did for Greenwich for 1887.

In his next paragraph the Astronomer Royal shows how the 'Orthodox' tackle the problem. He admits that 'systematic errors of one sort or another' are assumed to be attributable to individual instruments and got rid of by averaging out the observations from the different observatories. Thus it appears that an 'orthodox' approach to the subject of individual zenith displacements, caused by the precessional rotation and differing with the latitude of each observatory, is not even contemplated.

With regard to his dictum that Draysonians must explain the dynamical principles governing the movement of the earth's axis, I feel that not all scientists will agree. Drayson disclosed some facts of far-reaching importance, and these according to our ability, we have confirmed. It is for the mathematicians to test them dynamically; and that, not with the rule that served their forefathers, but by a new investigation and with open minds. (N. M. McLeod)

Sir,—In reply to the letter of the Astronomer Royal on what he still calls 'The Drayson Heresy,' the supporters of the alleged heresy still contend that they are not being given a square deal, and they will not concede that formal geometri-

cal construction, for the correctness of which ample evidence exists, should be compelled to give way to a complex dynamical theory in which a number of variables are involved and which leads to no certain conclusion in regard to the vitally important matter of periodicity while at the same time only fixing a maximum for the radius of precession. Whatever its value it fails entirely to account for the changing obliquity as measured by Newcomb. The Drayson theory, on the other hand, gives a completely satisfactory geometrical explanation of the rate and amount of change by taking the axis of the precessional cone as being 6 degrees off the vertical, taking the plane of the ecliptic as horizontal. If a cataclysm had occurred which was powerful enough to throw the said axis off the vertical it might well take aeons of time for the sun to restore it to its original position. The observation at the end of the Astronomer Royal's article that even if the axis of the precessional cone had been thrown out of the vertical the earth's pole would still move round the pole of the ecliptic simply does not make sense, for the alteration of the axis of the precessional cone would carry with it a corresponding alteration in the inclination of the earth's axis. It is unreasonable to allow for the possibility of such a cataclysm and then deny its inevitable result.

The situation as it now appears is that the Astronomer Royal has virtually constituted a court to try Drayson in his absence with himself as judge, in spite of the fact that he is in strong sympathy with the prosecution and equally strongly prejudiced against the defence. Under these conditions it would be as well if the learned judge would emulate Drayson in having a one-track mind and confine the attention of the court to the fundamental issue before it instead of permitting the prosecution to drag a number of red herrings in various stages of decomposition across the all-important main track, each of which has to be followed up and deodorised before the court can proceed to transact its proper business. The main track is the claim made by Drayson and his supporters that he discovered a geometrical construction of the earth's polar motion which enabled him to forecast the position of important stars over half a century in advance with uncanny accuracy. It may be mentioned here that the deviations of the beam stars mentioned in my December article should have read—2.23 and x 3.6 seconds, not minutes. In point of comprehensiveness, whether true or false, Drayson's theory is far in advance of anything claimed by orthodox astronomers, and for the Astronomer Royal to apply such adjectives to it as empirical, arbitrary, and ad hoc is to wrest plain English words from their accepted sense and to show himself to be animated by a most unjudicial bias. It might well be debated by the Brains Trust as to whether it is permissible to speak of an empirical theory without being guilty of a contradiction in terms. Most discoverers reach their results by empirical trials and errors combined with intuitions and postulations, but once they have established a prima facie case for the existence of a comprehensive law they have progressed far beyond the stage of empiricism. Similarly a comprehensive law covering a wide area of facts cannot possibly be called ad hoc, for this is an adjective descriptive of an explanation or justification used to account for a special case. As for arbitrariness, the charge preferred against Drayson of having succumbed to it comes ill from the Astronomer Royal whose letter literally bristles with arbitrary and unprovable assertions. His statement that he has perused Drayson's books at first hand is, of course, accepted, but if he has grasped the fundamental principles set forth in the same he has consistently avoided facing up to them. Whether the earth's axis has a double conical movement or not does not affect the soundness of Drayson's theory in any way. At this juncture the learned judge intervenes to deliver a slashing attack on the defunct culprit which is vociferously applauded by counsel for the prosecution and his juniors. Counsel for the defence begins to wonder uneasily whether after all his defunct client had

been deficient of the mental equipment needed to invade the hallowed precincts of astronomical science. Thenceforward the procedure of the court takes on an increasingly Gilbertian complexion. Sutcliffe's book, we are told, is not worth the paper it is written on. But by a simple geometrical diagram he proves his point that a decrease of obliquity involves a precessional movement of the pole of the ecliptic in a direction opposite to that produced by the pull of the sun acting upon the equatorial bulge of the earth. Graphical demonstrations are of great value in mathematics. Then we learn that Dayton Miller's experiments on ether-drift have been weighed in the balances and found wanting. Presumably the more precise apparatus which has brought Miller to his doom is the quartz crystal oscillator plus the elinvar rod used in an experiment carried out at the National Physical Laboratory at Teddington in 1937 to ascertain whether the theory relating to the Fitzgerald Contraction could be substantiated or not. Undoubtedly this apparatus could be adapted to ether-drift experiments, but in that case it would have to be taken up to a height of several thousand feet to avoid the masking of results by ether-drag. Morley and Miller got only small figures for the relative velocity of earth and ether when they worked at a low level in 1902-04, but when the latter took observations from the top of Mount Wilson at a height of 6,000 feet he obtained a positive and consistent figure of 10 km. per sec. Incidentally it may be mentioned that in the latter series of experiments which were carried out in 1925, 100,000 turns of the interferometer (the testing instrument) were made, and in the next year the entire series was repeated and the same result obtained. It was not necessary to take up the quartz crystal oscillator to a height to obtain reliable results. Professor Fitzgerald, of Dublin, was a firm believer in the relative movement of earth and ether, and when the Michelson-Morley experiments were carried out in 1887 to obtain a figure for this movement, but failed, so it was believed, to get any positive result, Fitzgerald came to the conclusion that the interferometer might be at fault because it might conceivably become shortened in the direction of motion. Had he lived, however, until 1925, when a large positive figure was obtained, he would have promptly scrapped his theory as having no longer *raison d'être* or value. Thus the Teddington experiments were directed towards administering a flogging to a dead horse, and consequently a null result was obtained. I still adhere firmly to my statement that dynamical theories need to be handled with discretion or more accurately with discrimination when it comes to finding an integral to express the synthetic interaction of a goodly number of variables. The mathematics involved are exceedingly complex and often necessitate making unprovable assumptions in order to obtain any integral at all. But judging from the account given by the Astronomer Royal of the genesis of the Newcomb formula for precession it was evolved without any reference to the figures given by Laplace and Stockwell for the combined planetary perturbations. In point of fact the precessional cycle caused by these perturbations is said to be so lengthy, not less than a million years, and the radius of 1-1/2 degrees is so small, that its effect upon the plotted curve of the Newcomb formula would be negligible. The supporters of Drayson accept without query the dynamical explanation of what might be called the Newtonian element in the precessional theory which takes no account of changing obliquity. And as regards producing a dynamical theory to account for the changing obliquity orthodox astronomy has nothing better to offer than the Draysonians. It accepts the Newcomb formula because it works within certain limits, which is the important thing.

As regards the criticism of Drayson's abilities and intellectual capacity made by the Astronomer Royal, this method of conducting scientific controversies is generally condemned by fair-minded people as provocative and unproductive of useful results. In the estimation of Drayson's followers his handling

EOA-003 ASTRONOMICAL OBSERVATIONS

of the Theory of the Precession marks him out as having possessed intuitive genius, apart from the fact that he had mastered all the elements of astronomy needed to enable him to develop his theory with professional exactness and discretion. The real offence which caused contemporary astronomers to treat him with discourtesy, contempt, or indifference, was that he had presumed to formulate and defend a theory which failed to harmonise with the preconceived notions and prejudices of the inner circle of the Elect, and consequently he had to pay the penalties exacted from most adventurous spirits who think ahead of their generation. (S. T. Cargill)

EOA-003 IRREGULARITIES IN THE EARTH'S ROTATION - - II

Gold, T. ; Sky and Telescope, 17:284-286, April 1958.

Many catastrophists subscribe to the idea that the earth's poles of rotation may have shifted drastically during the geological eons. Gold, an eminent scientist, discusses the dynamic problems and the evidence.

The rotation of the earth is not quite steady. Both the length of the day and the direction of the rotational axis are subject to certain changes, as told in last month's installment. The discussion is summarized in the table here. In which the different kinds of wobble and of speed changes are sorted out according to the time scale on which they occur.

There is just one section of this table that we have not yet dealt with, the one for axis wobble occurring in the very long times covered by the geological record. How much have the poles moved in geological times? Has there always been just a little wobble such as we know today, or has there been a steady drift over distances large enough to Interchange polar and equatorial regions?

If these questions cannot be answered, then much of the geological record cannot be interpreted. Very large changes have taken place in the climates of different regions. Several areas now in warm climates were once under ice: India, parts of Africa, South America, and Australia. Over periods of 50 or 100 million years, many places seem to have changed their climate from one extreme to the other, from tropical to polar conditions, from desert to swamp.

These effects cannot be explained in the same way as the minor general climatic variations that account for the growth and shrinkage of the polar ice-caps in the last million years or so. Clearly, no growth of the icecaps could account for the glaciation of India, if that country were where it is now, especially since we know that other areas were not glaciated at that time. But are we allowed to attribute these great glacliatlons of long ago, of regions now tropical, to a large drift of the earth relative to its rotational axis, bringing these regions successively to a pole?

This question has been discussed from time to time by geophysicists, notably Sir George Darwin and Lord Kelvin. They considered it unlikely or impossible for any large change to have taken place. But we now recognize some faults in their arguments, and new knowledge concerning the structure of the earth has altered the picture. For this reason I came to disagree with their conclusions, and reopened the discussion in 1955.

Changes in the Earth's Rotation

Time Span Years	Wobble of Axis		Length of Day	
	Amount	Causes	Amount	Causes
1	Up to 12 meters	Shifts of air masses	0.001 sec.	Winds.
10	About 3 meters	Sea-level changes? Changes in core?	0.001 sec.	Changes in core.
1,000	(Unrecognized, but could be 300 meters)		0.01 sec.	Sea-level chgs. Tidal friction. Separation of materials inside earth.
10 (Geological times)	90 degrees	Shifts of masses on crust. Possibly Interior changes.	Unknown	Gravitational sorting of material. Oceanic tides. Atmospheric tides.

Let me make it clear that there is no general physical law that prevents a body from turning over with the aid of internal forces only. The general law of the conservation of angular momentum merely prohibits a change of the value and direction in space of the body's angular momentum unless acted upon by an external force; but it has nothing to say about the orientation of the body relative to that direction. For instance, if a cat is dropped headfirst, it will contrive to land on its feet. Similarly, there is no fundamental difficulty connected with a large-angle polar movement, and we must merely see what disturbing internal forces have been available in geological periods and how big their effects are likely to have been.

If the earth were a sphere and not an oblate spheroid, then it would possess no stability at all against toppling over. A slight shift in mass would alter its orientation by a large angle. The actual stability of the earth is due to its spin, and to its equatorial bulge which gives it the property of a gyroscope. If the shape of the earth itself were unalterable, then this stability would be very great and all the upheavals of geology would have disturbed the axis by less than a degree. But is it reasonable to assume the earth is stiff enough to maintain its shape over long periods?

If it were that stiff, how does the earth happen to have the correct shape for its present speed of rotation? Why is the equatorial bulge not too big or too small? If the flattening at the poles were too small or too great, there would be a tendency for the oceans to concentrate in either the polar or equatorial regions, but this does not occur. Refined measurements tell us that almost exactly the right amount of bulging has occurred to make the globe's surface one of equilibrium. The present shape of the earth would not be the right one for a different speed of rotation. As we learned last month, however, the rotation may have altered drastically in the past. Therefore, we must suppose that the globe was later able to adjust itself to the proper shape, that is to say, it must be capable of a certain amount of plastic deformation.

Of course, here we are concerned with the main shape of the earth, and must not be confused by the high degree of stiffness possessed by the very thin outer crust. The crust is under very different physical conditions from the interior, and it is no guide at all to the properties of the internal material. The crust's stiffness is a very localized phenomenon—geological processes have succeeded in breaking up the crust almost everywhere, even folding and

contorting it—and this broken outer crust does not even contribute to the stiffness of the whole body over long periods of time.

What, then, is the behavior of a spinning, bulging earth of such plasticity that it cannot indefinitely maintain a shape different from the equilibrium one? If on such an earth large masses were to move from one place to another, then the balance would be changed and the axis would immediately move by some small angle. But the earth now would be spinning around an axis for which it did not possess the precise equilibrium shape, and it would proceed to adjust its shape accordingly.

But it is only the original spheroidal shape that can prevent the globe from toppling over farther in the direction in which the unbalance is pulling it, so, as the shape adjusts itself, the toppling over proceeds. The process must then continue until the unbalance has disappeared, and this can only happen when the redistributed masses have changed significantly their relation to pole and equator. If, for instance, an extra mass had been placed at some intermediate latitude, the toppling over would have to proceed until this extra mass was located on the equator.

However, another well-known fact complicates the foregoing argument. The plasticity of the earth required to allow it to topple over would actually let the extra mass sink in, and the unbalance would therefore disappear. The big mountain chains, for example, are not surplus masses placed on a uniform earth. They are, in fact, regions where the material is a little less dense than average down to a depth of some tens of kilometers, and their equilibrium (floating) position therefore leaves them a little high. The mountains are in the same sort of equilibrium as pack ice is at sea. Geophysicists refer to this as isostatic equilibrium.

This isostatic adjustment means that, while we cannot consider the effect of an extra mass, we can still discuss the unbalance of the earth that results from the surface masses being of different densities and "floating" at different depths in the plastic material below. The center of gravity of each of these blocks could change its height as a result of, say, erosion or some process of mountain building, and this would produce an unbalance of the earth as a whole. For any given configuration of such floating blocks of crust, there would be one particular axis of rotation for which, after adjustment of the shape, the body could achieve a greater moment of inertia than for any other axis. The earth would then topple over gradually in such a direction as to make that the axis of rotation.

It now remains to decide at what rate such a process might have been going on. Would it come within the geological time scale, or would it be much slower? Let us consider first the amount of unbalance and then the degree of plasticity of the earth's body.

There might be an unbalance arising from processes in the interior of the earth, but we do not have much information about that. Of the known processes, the most significant are undoubtedly the building of mountains, the ups and downs of continental blocks, and the erosion and probable growth of continents. A reasonably good estimate of the unbalance so produced can be made from geological data.

As for the plasticity, the present adjustment of shape to rotation speed indicates that the plasticity is enough to allow some adjustment in geological periods. However, the 14-month wobble of the earth, described last month, can give us a more definite value. With a perfectly elastic or perfectly stiff body, this component of the variation of latitude would have to be quite regular. If there were random exciting impulses, they would continue to build up the amplitude of the motion indefinitely. But, despite irregular disturbances, the motion remains small, proving the existence of some form of nonelastic dissipative behavior of the material. It is not far-fetched to identify this nonelastic property, required

for the damping of the 14-month wobble, with the plasticity that permits the earth to conform to the figure of rotation.

It can be shown that the nonelastic behavior must be resident in the main solid mantle of the earth (see diagram above), and not in its liquid core, as was thought at one time. Moreover, such plasticity is a common property of substances that are heated nearly to their melting points, and we think that much of the solid part of the earth is in this condition. From the degree of irregularity of the 14-month wobble, the plasticity can be evaluated. Then, by using the data concerning geological disturbances, an approximate value can be derived for the rate of possible polar movement.

Walter Munk's calculations confirmed my earlier work, and showed that a time between 10 and 100 million years would be required for the earth to turn over by a large angle, say 90 degrees. This is well within the geological time scale. Would a large polar drift therefore help explain the geological record?

Many geologists have favored a theory of continental drift, thinking that the main masses of the continents have shifted their relative positions by large amounts. Of course, there is nothing in the discussion about polar wander to suggest that continental drift has not taken place, although some of the arguments in favor of continental drift can be met by polar drift alone. There is other evidence, however, that seems to require both phenomena.

We can easily have polar wander without continental drift, but, except under the most artificial assumptions regarding the earth's interior, continental drift cannot occur without polar wander. The material under shifting continents would have to be so plastic that polar wander must certainly be expected as well.

Movement of the earth's outer crust as a whole, relative to the interior, has also been suggested as effectively moving the poles. This idea is a little like continental drift, except that all the surface moves together. Again, this is dynamically possible, but it requires a degree of interior plasticity that would itself allow a yet more rapid turning over of the entire earth by the processes already discussed. An interior so plastic that it would allow its skin to slip would itself have too little stability to resist turning over.

Will we ever know in detail what happened in the remote past? The geological evidence is suggestive but not sufficiently definite. However, in the last few years the answers have begun to come from a new technique—investigation of the magnetism of ancient rocks.

When lava pours from a volcano, it contains grains of iron-oxide minerals, and while these are still very hot their magnetism is easily aligned by the earth's weak magnetic field. In many rocks, once they have cooled, this orientation cannot be altered by a subsequent change in the earth's field. Thus, the magnetized particles act as tiny compass needles, preserving for future ages a record of the geomagnetic field at the time of the rock's formation.

Another way in which some rocks may preserve their magnetism of long ago is by sedimentation. Magnetized particles are brought into alignment with the earth's field at the time of the deposition of the sediments.

These investigations have shown that in geologically recent times the average direction of the magnetic axis of the earth has coincided quite accurately with the rotational axis, even though at any one time there may be a considerable excursion. This provides a strong reason for supposing that the two axes always tend to go together over long periods. Therefore, analysis of numerous rock samples from one area and one period can give a good indication of the position of this area relative to the earth's rotational axis at that time. Different areas can be compared for the same period, to see whether or not they agree in specifying a particular position of the pole. If they agree, polar wander is indicated; if they do not, then areas of the crust must have moved relative to one another,

providing evidence for the theory of continental drift.

Such data are being gathered at the present time, mainly by workers in Great Britain and Australia, and they have surveyed material from different epochs in the British Isles, America, Iceland, India, Australia, and other places. The evidence, when interpreted in the way we have discussed, is that polar wander has certainly taken place. There is no doubt that ancient rocks show very different directions of magnetization from recent ones, and such changes would seem to indicate that the North Pole must have moved in the last 500 million years from somewhere in the middle of the Pacific Ocean, by way of eastern Asia, to its present position. But there are some regions on the earth, especially in the Southern Hemisphere, where the direction of magnetization does not fit a simple polar movement, so substantial amounts of continental drift are also indicated.

These methods of paleomagnetism are very powerful, and many checks can be made for internal consistency of the data. In addition, geological information about climate is usually in good agreement with the magnetic data. Most likely, therefore, the earth has really been as unsteady a place as the magnetic record of the rocks would seem to show.

All this discussion started, last month, with the very precise measurement of very small effects. What I find so fascinating in this subject, however, is that the small effects are not measured merely to know something very precisely, but to learn about the very large effects that have taken place in the long history of the earth.

Comparison of Geomagnetic Latitudes with Ancient Climates*

Periods	Eastern U. S. A.—Curve II		Western U. S. A.—Curve III	
	Latitude	Climatic Indicators	Latitude	Climatic Indicators
Silurian to Mississippian	10° - 30'	Red beds, thick salt and gypsum deposits, coral limestones, dolomites	0° - 10°	Thick coral limestones, dolomites
Pennsylvanian and Permian	0° - 20°	Gray sediments, thick coals, types laid down in hot and humid climates	10° - 30°	Red beds with thick salt and gypsum deposits, large coral reefs
Triassic and Jurassic	10° - 30'	Red beds with salt deposits	10° - 30°	As above

*Taken from E. Irving, "Palaeomagnetic and Palaeoclimatological Aspects of Polar Wandering," Geofisica Pura e Applicata, 33, 23, Milan, 1956.

SECTION ER: UNUSUAL ROCKS

Most of this sourcebook concerns stratigraphy, topology, and other large-scale aspects of geology. Looking toward the small, in this section are collected instances of single rocks and localized areas that are peculiar in some respect. Most entries here have only curiosity value and do not suggest inherent weaknesses in geological theory. The tektites may be an exception, for possibly they are still one more manifestation of terrestrial catastrophism.

- ERA Anomalous rocks. Spherical rocks, unusual crystals, odd concretions, vitrified areas, dry quicksands, and sundry other items.
- ERG Graphic markings. Peculiar patterns, ostensibly of natural origin, found on rocks.
- ERM Meteorites and tektites. Only the stranger meteorites are included.
- ERR Ringing rocks. Also sounding stones.
- ERS Musical sands. Sonorous sands, barking sands, whistling beaches, etc.
- ERV Moving rocks. Rocks that move across the surface, presumably due to the action of wind, gravity, and other natural forces. Rocks that seemingly erupt from below the surface.

UNUSUAL ROCKS

The ERB subsection is the province of rocks and localized geological deposits that are peculiar in size, shape, constitution, arrangement, etc. It is a diverse bag of oddities, and if the reader can discern anything significant in this collection (above and beyond its curiosity value) he is most welcome. Note that unusual meteorites and the so-called tektites are to be found in subsection ERM.

ERB-001 PATRICK COUNTY, VA., AND ITS CURIOUS "FAIRY STONES"

Bouldin, Powhatan; Scientific American, 79: 394-395, December 17, 1898.

All the things that I have enumerated are highly interesting, but nothing that I have seen in Patrick County has interested me so much as its fairy stones.

These curious little crystals are found in only three other States besides Virginia, in no other county in Virginia but Patrick, and nowhere else in Patrick but on and along Bull Mountain, a spur of the Blue Ridge running twenty miles through the county. The fairy stones found elsewhere, judging from the specimens exhibited at the Atlanta and Nashville expositions, are not at all comparable to those found on Bull Mountain. To a few of the people of Patrick they have been known for a long time, but not until about ten years ago did they come into public notice. Some of these stones which have been analyzed contained titanite, tourmaline, garnet, aluminum, and steatite, titanite being the principal material.

Geologists say that they are crystals. Most of them have crosses, some what is called the Roman; some, the Maltese; some, the St. Andrew's; and some, crosses for which there are no names. Those which have no crosses are pretty stones of different forms. Frequently two, sometimes three or four, are joined, making a most curious combination. Possibly a person skilled in the use of the chisel might imitate what might be styled the plain work of the fairies; but it would be impossible for the most skillful sculptor to imitate their fancy work. On many of these stones there are crosses exactly alike on opposite sides. Some of the stones are not larger than the head of a pin, while others weigh as much as an ounce and a half. No two are alike. Nature seems to have tried her hand at variety in making them, as she does in making the leaves on the Otaheite mulberry tree. And they are of every shade of color. A number of them placed upon a cardboard make a picture as novel as it is strange and beautiful. No adequate conception can be formed of what a great curiosity fairy stones are without seeing a great many of them together.

Hunting for fairy stones is a new and charming diversion. A walk of two and a half miles from Stuart will take you to where they are found. You will have to climb the mountain, but the scenery along the route is so picturesque that you will forget you are going uphill. And, besides, you will be constantly thinking: What shall I find? Will it be a Roman, a Maltese, or a St. Andrew's? Or will it be a Roman joined to a Maltese or a Maltese joined to a St. Andrew's? or a St. Andrew's joined to one of the crosses for which there is no name? Of one thing you may rest assured, and that is, that every stone that you may find will be different from any that you have ever seen.

When you arrive at the place (it is only about in spots on Bull Mountain that fairy stones are found), you will begin at once the search. You will find them from two to four inches under the ground, and the best instrument to use in digging them up is a small trowel. You will find them in abundance; but the really pretty ones, such as are used by ladies for scarf pins and by gentlemen

ERB-002 ANOMALOUS ROCKS

for watch charms, are scarce. All of them, however, are interesting specimens of the most curious form of crystallization.

When you have filled your pockets, you start back; but you will not go far before you will be tempted to take a seat on one of the large, flat rocks on the side of the road—not to rest, for it is now *facilis descensus*—but to gratify the curiosity which you are sure to have to look over your treasure. Taking out your fairy stones and inspecting them, one by one, you will discover in many of them beauties which escaped your notice while you were digging them out of the ground.

ERB-002 COMMUNICATING WITH LIFE IN SPACE

Cade, C. M. ; Discovery, 24:36-41, May 1963.

On the assumption that the Earth was visited in the past by the space-probes or explorers of older races, it is natural to ask why there is no evidence of these visits, although it is perhaps not remarkable if a few visits, confined to limited areas (perhaps now beneath our oceans), and of brief duration, have left no traces. The chances of finding any preserved traces are vanishingly small, and it is possible that we might not recognise them if we found them. We have many examples of unexplained objects and events from different parts of the geological record, one of these being the article known as Dr. Gurlt's Cube. This mysterious object was discovered in 1885, and descriptions of it were published in several scientific journals. It had been taken from a block of coal of the Tertiary epoch, in which it had presumably been burned for some tens of millions of years. It was almost a cube, two opposite faces being rounded, so that the dimensions were 67 mm x 47 mm. (the last measurement being between the rounded faces). A deep incision ran all round the cube near its centre. The weight of the object was 785 grams (26 ounces), and in composition it resembled a hard nickel-carbon steel. The sulphur content was far too low for it to be any kind of natural pyrites. Various specialists who examined the cube thoroughly were unable to agree on its origin. Some considered it to be a fossil meteorite; others thought it was a meteoritic iron mass modified by human agency; still others said that it was definitely artificial. The object, still unexplained, is now in the Salzburg Museum, (p. 41)

This famous cube is the subject of several papers reproduced in this and the Series M sourcebook, for its origin may be natural or artificial.

ERB-003 DATING THE LIBYAN DESERT SILICA-GLASS

Oakley, Kenneth P. ; Nature, 170:447-449, September 13, 1952.

In the Libyan desert and several other spots around the world, large deposits of glassy material have long puzzled geologists. The Libyan field is rather large and perhaps relates to some recent catastrophe.

Pieces of natural silica-glass up to 16 lb. in weight occur scattered sparsely in an oval area measuring 130 km. north to south and 53 km. from east to west, in the Sand Sea of the Libyan Desert. This remarkable material, which is almost pure (97 per cent SiO_2), relatively light (sp. gr. 2.21), clear and yellowish-green in colour, has the qualities of a gemstone. It was discovered by the Egyptian Survey Expedition under Mr. P. A. Clayton in 1932, and was thoroughly investigated by Dr. L. J. Spencer, who joined a special expedition of the Survey for this purpose in 1934.

The pieces are found in sand-free corridors between north-south dune ridges, about 100 m. high and 2-5 km. apart. These corridors or 'streets' have a rubbly surface, rather like that of a 'speedway' track, formed by angular gravel and red loamy weathering debris overlying Nubian Sandstone. The pieces of glass lie on this surface or partly embedded in it. Only a few small fragments were found below the surface, and none deeper than about 1 metre. All the pieces on the surface have been pitted or smoothed by sand-blast. The distribution of the glass is patchy. It was found to lie most thickly around the expedition's Camp 7 (lat. $25^\circ 17' 541''$ N., long. $25^\circ 34' 0''$ E.). At several places there were groups of flakings, evidently where large lumps had been broken up by man. Only two small fragments were found upon the dune ridges. They occurred in company with an implement of quartzite and had evidently been carried there. One piece of silica-glass was found 240 km. south by east of the main area of distribution, and another piece 225 km. to the east-south-east. These, too, had probably been transported by man.

While undoubtedly natural, the origin of the Libyan silica-glass is uncertain. In its constitution it resembles the tektites of supposed cosmic origin, but these are much smaller. Tektites are usually black, although one variety found in Bohemia and Moravia and known as moldavite is clear deep green. The Libyan silica-glass has also been compared with the glass formed by the fusion of sand in the heat generated by the fall of a great meteorite, for example, at Wabar in Arabia and at Henbury in Central Australia. Reporting the findings of his expedition, Dr. Spencer said that he had not been able to trace the Libyan glass to any source; no fragments of meteorites or indications of meteorite craters could be found in the area of its distribution. He said: "It seemed easier to assume that it had simply fallen from the sky".

It would be of considerable interest if the time of origin or arrival of the silica-glass in the Sand Sea could be determined geologically or archaeologically. Its restriction to the surface or top layer of a superficial deposit suggests that it is not of great antiquity from the geological point of view. On the other hand, it has clearly been there since prehistoric times. Some of the flakes were submitted to Egyptologists in Cairo, who regarded them as "late Neolithic or pre-dynastic". In spite of a careful search by Dr. Spencer and the late Mr. A. Lucas, no objects of silica-glass could be found in the collections from Tut-ankh-Amun's tomb or from any of the other dynastic tombs. No potsherds were encountered in the silica-glass area, but in the neighbourhood of the flakings some "crude spear-points of glass" were found, also some quartzite implements, "quernstones" and ostrich-shell fragments.

From the meager geological and archeological evidence Oakley concludes that the Libyan glass deposits probably originated with "glass meteors."

ERB-004 ANOMALOUS ROCKS

ERB-004 A DRY QUICKSAND

Anonymous: American Meteorological Journal, 3:4-5, 1886.

In the southwestern corner of the desert of southern Arabia, north of the western end of Hadramaut, and approached from the little village of Sawa, is a very remarkable spot described by Wrede from his visit in 1843, whose description is reproduced in a recent number of the Revue coloniale internationale. There are here, in the waste of yellow sand, several spots covered by a grayish white dust, which swallow up every object thrown into them. One of these spots, described by Wrede, is about two miles long and a little less in breadth. It sinks gradually toward the middle and is apparently due to the work of the wind. Wrede approached it with the greatest care and sounded it with his staff. The edge is stony and falls away suddenly. When the staff was thrust into the fine material beyond the edge, almost no resistance was felt and it was as if the staff had been thrust into water. When it was passed through the fine dust lengthwise the resistance was almost imperceptible. A stone of two pounds weight or more was fastened to a cord sixty fathoms long and thrown in as far as possible. It sank at once and with increasing velocity so that at the end of five minutes the end of the cord had disappeared. The presence of Bedouins prevented any more observations. The natives believe that great treasures are buried here and are watched over by genii who pull down into the depths the unwary treasure-seeker.

ERB-005 [THE ARABIAN HARRAS]

Velikovsky, Immanuel; Earth in Upheaval, Dell Publishing Co., New York, 1965.

The geological character of the Arabian harras is strange indeed; but Velikovsky's meteoric origin seems extreme. However, see ETC-OOT for a description of the Wobar crater and associated glass deposits.

Twenty-eight fields of burned and broken stones, called harras, are found in Arabia, mostly in the western half of the great desert. Some single fields are one hundred miles in diameter and occupy an area of six or seven thousand square miles, stone lying close to stone, so densely packed that passage through the field is almost impossible. The stones are sharp-edged and scorched black. No volcanic eruption could have cast scorched stones over fields as large as the harras, neither would the stones from volcanoes have been so evenly spread. The absence, in most cases, of lava—the stones lie free—also speaks against a volcanic origin of the stones.

It appears that the blackened and broken stones of the harras are trains of meteorites, scorched in their passage through the atmosphere, that broke during their fall, as bolides do, or on reaching the ground. Billions of stones in a single harra indicate that the trains of meteorites were very large and can be classed as comets. Despite alternate exposure to the thermal action of the hot desert sun and the cool desert night, the sharp edges of the stones have been preserved, which shows that they fell in a not too distant period of time. Following the procedure adopted in this book, literary references to the harras of Arabia in ancient Hebrew and Arabic literatures will not be dealt with here.

Meteorites that fall on the earth are of two kinds. One consists of iron with an admixture of nickel; by means of this admixture and the characteristic pattern seen in the cut surface of such stones, their meteoric origin can be easily established. The other group, probably larger than the first, does not differ in its composition from the rocks of the earth and cannot be distinguished unless the fall has been observed, or, as in the case of the stones of the harras, their scorched and broken condition, together with their occurrence in large fields, speak for their extraterrestrial origin.

Larger bodies than the stones of the harras fell on Arabia, too. In Wobar in the desert there is a meteoric crater with meteoric iron and silica glass spread around it.

Large rivers that disappeared, numerous volcanoes that burned and were extinguished, blackened stones that fell in areas each of them a hundred times larger than any volcanic eruption could have covered and meteoric iron spread around a large crater—all of these bespeak great upheavals in nature in recent as well as earlier ages, to which the vast peninsula of Arabia was more than once subjected. (pp. 96-97)

ERB-006 FITTING BOULDERS

Shelley, David; Nature, 227:1377, September 26, 1970.

Since the publication of my note on fitting boulders in New Zealand, Hills's descriptions together with correspondence I have received make it clear that the phenomenon is very widespread. Examples from the north Yorkshire coast had been noted by C. Simms, curator of natural history at the Yorkshire Museum, and the following extract from a poem he wrote in 1966 well describes them

"Notice how these sea-shored boulders pack,
not all-sprawled as spate rivers leave them,
but crazy-built, seamed by crablind crack.
With age they wear closer to one another."

Hills disagrees with my suggestion that salt or Ice crystallization is a principal agent involved, and he ascribes fitting boulders to Wave action. In my note, I was careful not to rule out wave action as a contributory process: nevertheless, I believe the evidence argues against it being the prime force involved. Hills pointed to examples of fitting boulders at mean sea level where they never dry out, but he is mistaken in believing this necessarily precludes salt crystallization. In the presence of a hot dry wind the rate of evaporation could be such that continual wetting merely leads to replenishment of salt solution, salt crystallization being increased rather than retarded.

Hill's statement that there is a relationship between wave force and the maximum size of fitting boulders needs proper exemplification before it can be accepted. As he indicates, the situation is complex, the maximum size depending not only on wave force but also on height above sea-level. I would add to this the following complexing factors: the size of the original boulders, since clearly the maximum size of fitting boulders cannot be greater than that of the source material; whether or not the piles of boulders are on firm bedrock or shifting fine material; the fabric of the boulders; the resistance of the various lithologies to weathering processes in general. The maximum size of fitting

boulders at all the localities at which I have observed them has simply been the maximum size of the boulders present at those localities.

The ideal location to test the relative importance of salt ice crystallization and wave action in the production of fitting boulders would be a freshwater lake where ice crystallization is unknown or rare and salinity always low.

ERB-007 SOLVING THE MYSTERY OF MEXICO'S GREAT STONE SPHERES

Stirling, Matthew W. ; National Geographic Magazine, 136:293-300, August 1969.

Stirling begins by describing his archeological researches on the man-made stone spheres of Mexico and Costa Rica (See Series M sourcebooks), and how a mining engineer steered him to the peculiar spheres described below. The setting is Jalisco State, in West Central Mexico.

We drove to the ruins of the old mine headquarters, then climbed on foot to an elevation of about 6,000 feet. There, atop a mountain spur, lay the five spheres.

Three of them were half buried, the fourth, washed clean of rubble, stood in an arroyo, and the fifth perched on the top of the ridge. It had a bulge on one side, it was split in two, as if broken while being shaped and left incomplete. All appeared to be made of soft volcanic stone similar to the mountain itself.

The following morning we began digging out the three half-buried spheres and in their vicinity found six other buried ones. We discovered 11 more large stone balls the following day, bringing the total to 22 at this site. They varied in diameter from four-and-a-half to six-and-a-half feet.

On the flat excavation area someone, sometime, had built a small rectangular foundation of stones. We could not determine its age, but it seemed an ideal spot for a ceremonial site.

I was nevertheless bothered by the fact that we found not one fragment of pottery or any other artifact indicating human occupation. And the spheres, though almost perfect in form, did not exhibit the fine surface finish of the Costa Rica specimens.

On the third day Jesus Lopez straightened up from his shovel and asked why we were doing all this digging and mapping.

"At Agua Blanca, just over the top of the hill," he said, "there are many, many of these balls lying in the open on the ground."

Still another site? I was skeptical at first, but decided to investigate. We arranged for horses in the village of Tiro Patria below the old mine entrance and set forth.

A two-hour ride took us up a mountainside through forests of oak, pine, and acacia with inspiring views of distant valleys. As the ground leveled off at the wild and lonely crest of the Sierra de Ameca, stone spheres came into view. First they appeared singly, then in clusters where they had accumulated in small arroyos—more and more, until we estimated there were hundreds.

A spectacular sight! The scene suggested some giant's bowling alley or the ball park of the Aztec gods. The spheres lay fully exposed; they ranged in diameter from about two feet to one giant of more than 11 feet. The average I

estimated at five or six feet.

The profusion of stone balls at Agua Blanca completely changed our concept of their origin. Such great numbers surely indicated natural formation. Some of the stones were pearshaped and a very few were joined as twins or had a dumbbell shape, and these sports certainly tended also to deny human fabrication.

But if the spheres were not man-made, then how had they been formed? Where had they come from in such fantastic numbers? We realized that our expedition had made an astonishing discovery—but that the explanation for it would have to come not from an archeologist but from a geologist. Convinced the spheres were naturally formed, Stirling consulted geologists, who reported as follows.

"The spheres were formed during the Tertiary geological period," Dr. Smith reported, "by crystallization at high temperatures in a matrix of hot ash-flow tuff. An avalanche of this hot ash, not a sifting down from the sky, overwhelmed the area.

"Crystallization of the Jalisco spheres," Dr. Smith continues, "began in nuclei of single glass particles. Gases released from the glass moved outward in all directions, promoting crystallization of adjacent glass particles and thus forming the spheres. This process continued until stopped by cooling or coalescence of spheres."

ERB-008 THE CANYON DIABLO METERORITES

Anonymous; Nature, 77:208, January 2, 1908.

The large quantities of "shale balls" in the Canyon Diablo area are peculiar enough to be Included in this sourcebook.

Part 11., vol. Iv., of the Smithsonian Miscellaneous Collections (p. 203, No. 1725) contains an interesting Illustrated discussion of the Canyon Diablo meteorites, by Messrs. G. P. Merrill and Wirt Tassin. The former discusses the distribution and physical characters of the "shale balls" found in such large quantities in the vicinity of the canyon in Coconino County, Arizona. These balls are roughly globular in outline, of all weights up to 50 lb., and consist of an exterior coating of hydrated oxide of iron frequently enclosing unoxidised Iron centres, or nuclei, the intermediate shell showing a green hydroxide of nickel mingled with oxides of Iron. The Inspection of a number of these balls and of the ground in which they are found apparently strengthens the theory of the meteoric origin of the crater.

Mr. Tassin deals with the chemical analysis of the "finds," and shows that these "shale balls" differ to some extent in their chemical composition from the ordinary Canyon Diablo iron. They contain appreciable quantities of chlorine, whereas none has been found in the ordinary "iron," and also contain more phosphorus; to the presence of these two elements the increased oxidation of the "shale balls" may be ascribed.

ERB-009 ANOMALOUS ROCKS

ERB-009 THE CONCRETIONS OF THE CONNECTICUT VALLEY

W., H. B.; Nature, 63:566, April 11, 1901.

The curiously-shaped concretions met with in the Champlain clays of the Connecticut Valley have for many years attracted attention. Indeed, so long ago as 1670 some specimens were sent to the Royal Society of London. A detailed description of them and of their mode of occurrence, illustrated by fourteen beautiful quarto plates, has now been issued by Mr. J. M. Arms Sheldon. Four principal types of concretions are met with; some are discs which call to mind the Kimeridge coal-money; some are cylindrical or club-like, one example (probably a compound one) being a little more than twenty-two inches long; others are botryoidal, and not a few are "queer little images" resembling "fishes, birds, ant-eaters, elephants, dogs, babies' feet," &c. (Fig. 1). [Figs, not reproduced!]

These occur in stratified river-drift clays, some of which are of a kind suitable for modelling, and some are more or less gritty. The most remarkable point is that "each clay bed has a form of concretion peculiar to itself," that is to say, the principal types are never found together. The author has seen "forty-eight specimens from one bed so similar it was impossible to tell one from another." Compound forms occur, where, for instance, two or even three discs have coalesced or been joined together (Fig. 2); and intermediate stages of such examples, and of immature concretions of horse-shoe type, are met with.

These remarkable bodies occur along the planes of bedding in the clays, and the lines of stratification may sometimes be seen to run in unbroken continuity through concretion and clay. In composition they consist of argillaceous and somewhat sandy limestone with small amounts of iron-oxide, magnesia and manganese oxide. They contain from 42 to 56 per cent, of carbonate of lime, whereas the clay possesses but 2 or 3 per cent. The concretions spread out laterally in the clay, as if water holding carbonate of lime in solution made its way along the planes of stratification; and unless in the case of tiny spheroidal concretions they are almost invariably flattened. No doubt they are due to the obscure process of segregation, whereby the mineral matter, tending to collect together, has been unable to assume definite crystallographic shape, but has concentrated itself in nodular form. Some of the concretions show evidence of concentric structure, but no appreciable nucleus has, as a rule, been seen, though it might have consisted of a particle of carbonate of lime. Evidently the concretionary process went on in a quiet way, but not always uninterruptedly, as indicated by the distinct stages of growth seen in some specimens. The shape of the concretions is held to be partly determined by the structure and composition of the matrix which holds it, and by the amount of carbon dioxide and other organic acids present.

On occasion, rocks bear strange impressions or designs that almost appear manmade. Of course, ancient man did incise rings, cupmarks, and numerous other designs in rocks (see series M sourcebooks) but the oddities reported here seem to have some natural origin.

ERG-001 NOTES CONCERNING A PECULIARLY MARKED SEDIMENTARY ROCK

Talmage, J. E.; Journal of Geology, 4:653-654, 1896.

The author describes and illustrates a fine-grained argillaceous sandstone, bearing peculiar surface markings consisting mostly of straight lines intersecting at right angles with almost mathematical precision. The deposit was examined by the writer in place, and an extensive collection of specimens was made under his direction by the "Utah University and Deseret Museum Expedition of 1895." The formation consists of undisturbed sedimentary deposit, referred to Trias or Jura-Trias age, and occupies a relatively low table land between the Kalparowltz and the Paria plateaus on the north of the Colorado River near Glen Canyon, Arizona. The bed of marked rock is almost two feet thick, and lies conformably between deposits of coarser sandstone, which show none of the rectilinear markings. While the most regular arrangement of the marks appears on slabs with perfectly flat surfaces, yet the rectilinear intersections are plainly shown on warped and ripple-marked surfaces. The lines are so regular as to suggest the possibility of human instrumentality when hand specimens only are examined.

ERG-002 PERCUSSION FIGURES

Escher, B. G.; Nature, 105:171, April 8, 1920.

C. V. Raman describes in Nature of October 9, 1919, percussion figures in isotropic solids. These figures are known in geology, and are found on rounded boulders of compact, homogeneous rocks, such as flint and quartzite. Albert Helm described in 1871 the "percussion-cones" (Schlageonus) brought forth artificially on pieces of flint by a powerful short blow with a hammer. F. Muhlberg, of Aarau (Switzerland) was perhaps the first geologist who described the percussion-figures (Schlagfiguren) on rounded boulders (1885). On some of the quartz-boulders from the River Aar, near Aarau, he found from hundreds to thousands of circular cracks, which he explained by the abrasion of boulders which formerly received coniform cracks through the numerous impacts during their transport through the river-bed.

ERG-003 GRAPHIC MARKINGS

These percussion-figures must be intersecting figures of cones and the surface of the boulder, and, therefore, will form, on sufficiently great boulders, nearly circles, ellipses, and parabolas. Muhlberg described thus percussion-figures arising from torrent-action, whereas A. Bigot (1907) emphasised that the "figures de percussion" arise from wave-action. He noticed them on the beaches of Basse-Normandie, particularly on quartzite boulders. Finally, P. N. Peach (1912) gave a very fine picture of the "bulbs of percussion" found on a rounded stone (chalk flint) dredged by the Michel Sars about 230 miles southwest of Mizen Head, Ireland. He pointed out that these figures indicate that "the stones had originally been dashed against each other by torrent- or wave-action."

Besides the term above-mentioned, Peach also uses the term "chatter marks," which seems to me less commendable, because this expression is also used by T. C. Chamberlin for a special type of glacial striae on the rock-bed. These curved figures were also described by Hagenbach in 1883, and afterwards called "arcs de Hagenbach" by L. Rollier.

ERG-003 MYSTERY IMPRINTS STUMP GEOLOGISTS

Anonymous; New York Times, November 12, 1948.

The origin of mysterious imprints strangely resembling fossilized dinosaur skin in the rock on the left side of United States Highway 9-W three miles north of the traffic light at West Cossackie, N. Y., confounded experts at the Geological Society of America's meeting at the Pennsylvania Hotel yesterday.

The marks were described as suggestive of "reptilian skin on a gigantic scale" as though a huge dinosaur had leaned against a mud bank and left the scaly imprints of his hide sometime in the earth's dim past.

"Fossilized dinosaur leather," as it is known to paleontologists, has been found in many parts of the world. The strange marks near West Cossackie, however, are in rock that are estimated to be 450,000,000 years old and the first dinosaur is reckoned to have made his appearance on earth 250,000,000 years ago.

The last surviving member of the dinosaur family perished more than 90,000,000 years ago, according to most scientific calculations.

The mysterious imprints were described by Dr. Chadwick, who discovered them from the window of his automobile while driving to Albany, as the repetition of units each about one and a half by three feet in size.

There are more than 100 of these individual "scales" and they are quite similar but not exact duplications of each other, Dr. Chadwick reported. The whole pattern occupies a space six by thirty feet, which is much larger than any known animal, he added.

The marks are pressed into a rock formation known to geologists as the Normanskill graywacke grit and shale. The specimen stands upright, clearly visible, a few feet from the road, which Dr. Chadwick said, had a wide shoulder convenient for parking at the spot.

Meteorites and tektites (which also may arrive on earth after a fiery trip through the atmosphere) are of geological importance in two ways: (1) very large objects may have created extensive impact structures (subsection ETC), and (2) tektites and their strewn fields provide an opportunity to date terrestrial catastrophes and analyze the events in some detail.

**ERM-001 ON THE SUPPOSED ENORMOUS SHOWERS OF METEORITES IN
THE DESERT OF ATACAMA**

F., L.; Nature, 41:108-109, December 5, 1889.

Two important points emerge from the following excerpts: (1) meteor swarms fall in highly elliptical patterns much like much of the falling material described in section GF; and (2) hearsay about spectacular events is likely to be greatly exaggerated.

During the present century nearly 300 meteoritic falls on the earth's surface have been observed, and on only a single date, namely August 25, 1865, has there been observed a fall on two distant parts of the earth on the same day. On that date stones fell at Aumale in Algeria, and at Sherghotty in India; but as the times of fall differed by about eight hours, and the stones arrived from different directions, it is more than probable that the coincidence of date was accidental. Hence we must infer that a swarm of meteorites, as far as actual observation of tangible objects goes, far from being hundreds of millions of miles long, with individuals a few miles apart, is a comparatively small group, separated from its neighbours, if it has any, by a distance comparable with the earth's diameter.

The extent of surface over which meteoric stones have been picked up after some of the best known and most widely spread falls is given in the following list:-

- Limerick, 3 miles long.
- Mocs, 3 miles by 0.6 mile.
- Butsura, 3 miles by 2 miles.
- Pultusk, 5 miles by 1 mile
- L'Aigle, 6 miles by 2.5 miles.
- Barbotan, 6 miles long.
- West Liberty, 7 miles by 4 miles.
- Stannern, 8 miles by 3 miles.
- Knyahlnya, 9 miles by 3 miles.
- Weston, 10 miles long.
- Hessle, 10 miles by 3 miles.
- New Concord, 10 miles by 3 miles.
- Castalia, 10 miles by 3 miles.
- Khairpur, 16 miles by 3 miles.

As far as I have yet been able to ascertain, the greatest observed separation has been sixteen miles. In the case of Macao, Cold Bokkeveldt, and Pillistfer, wider spreads have been chronicled, but later Information has shown the inaccuracy of the earlier statements.

It is a question of a certain amount of Interest as to whether there is any evidence of the actual fall of a shower of meteorites over a large extent of the earth's surface.

ERM-002 METEORITES AND TEKTITES

Such evidence has long been supposed to be furnished by the plentiful occurrence of meteorites in the Desert of Atacama, a term applied to that part of Western South America which lies between the towns of Copiapo and Cobija, about 330 miles distant from each other, and which extends inland as far as the Indian hamlet of Antofagasta, about 180 miles from the coast.

The generally received impression as to the occurrence of meteorites in this desert is well illustrated by the following statement of M. Darlu, of Valparaiso, read to the French Academy of Sciences in 1845:-

"For the last two years I have made observations of shooting-stars during the nights of November 11-November 15, without remarking a greater number than at other times. I was led to make these observations by the fact that in the Desert of Atacama, which begins at Copiapo, meteorites are met with at every step. I have heard, also, from one who is worthy of trust, that in the Argentine Republic, near Santiago del Estero, there is—so to say—a forest of enormous meteorites, the iron of which is employed by the inhabitants."

A study of the literature indicates that "the forest of enormous meteorites" near Santiago del Estero, understood by Darlu as significative of infinity of number, is really a free translation of a native statement "that there were several masses having the shape of huge trunks with deep roots," and that not more than four, or perhaps five, masses had really been seen in the Santiago locality at the time of Darlu's statement. There is a similar misunderstanding relative to the Atacama masses: it is clearly proved that, at a date long subsequent to 1845, the Desert was virtually untrodden and unexplored. In Darlu's time it was only crossed along definite tracks by Indians travelling between San Pedro de Atacama and Copiapo, and between the inland Antofagasta and the coast. In fact, it is established that the only Atacama meteorites then in circulation were all got from a single small area, three or four leagues in length, in the neighbourhood of Imilac, one of the few watering-places on the track between San Pedro and Copiapo.

Since that time the discovery of rich silver-mines in the centre of the Desert, and the working of the nitrate deposits, have led to vast changes; the Desert has been more or less closely examined, and other meteoritic masses have been found. Still, the number of meteorites yet discovered, distinct either in mineralogical characters or locality, is shown to be, at most, thirteen.

It is thus clear that the meteorites of the Desert of Atacama afford absolutely no proof that enormous meteoritic showers have ever reached the earth's surface.

ERM-002 NEW THEORY SHOWS MOON ONCE PART OF SOUTH AMERICA

Anonymous; Science News Letter, 37:303, May 11, 1940.

Thousands of small glassy objects, called "tektites," discovered on the southwestern shores of the Pacific Ocean are important evidence that the moon was once a part of the earth, according to a theory advanced by Dr. Carl W. Rufus, of the University of Michigan astronomy department.

These tektites have been studied by scientists for more than 150 years, but there has never been a satisfactory theory for their origin.

Dr. Rufus' explanation of the phenomena is based largely upon the general "fission" theory of the origin of the moon, developed by Sir George Darwin, and which says that the Pacific Ocean is a scar on the earth—created when the moon was torn away 10,000 years ago by a powerful tidal force.

Some of the loose matter which was pulled away with the moon did not fall back immediately to earth, Dr. Rufus says, but rather continued to revolve out in space for some time. These particles, he believes, were similar in composition to the matter which is contained in Saturn's rings today, and are the same glassy "tektites" found in the Pacific area.

ERM-003 TEKTITES ARE TERRESTRIAL

Faul, Henry; *Science*, 152;1341-1345, June 3, 1966. . (Copyright 1966 by the American Association for the Advancement of Science)

Faul summarizes the tektite evidence from the point of view suggested by the title. His conclusions are not accepted unanimously. Whatever their true origin(s), the existence of tektites seems to infer several large-scale terrestrial catastrophes.

To anyone who has worked with them, tektites are probably the most frustrating stones ever found on earth. For almost 200 years these glassy objects have been scientifically collected, studied, and subjected to every conceivable kind of analysis. A vast amount of data has been accumulated, but one still can draw only a very crude outline of the physical and chemical processes that formed the tektites. It has been established that tektite-like glass is produced in hypervelocity impacts on rocks; that tektites formed and cooled enough to be rigid before they entered (or reentered) the earth's atmosphere; and that aerodynamic ablation partly melted them again on their passage through the atmosphere. The exact process of tektite formation remains largely a mystery, but age measurements are beginning to show where this formation occurred. The violent controversy over a terrestrial versus an extraterrestrial origin for tektites is nearing its end.

The age of a tektite can be measured in several different ways. One may determine the amount of Ar^{40} that has accumulated from the decay of K^{40} , or one may develop and count the tracks left in the tektite glass by the spontaneous fission of U^{238} , or one may determine the present-day Sr^{87}/Sr^{86} and Rb^{87}/Sr^{86} ratios in the glass and extrapolate to the initial Sr^{87}/Sr^{86} ratio, drawing the strontium isochron. These three ages have different meanings. The potassium-argon method dates the time when argon diffusion in the glass became negligible compared to the rate of its generation from potassium decay. The fission-track method establishes the time of last cooling to a temperature where the tracks in the glass remain stable with time. If a tektite has been through a grass fire, for example, the fission tracks will date the fire. That is one reason why ages measured by the fission-track technique are occasionally lower than ages determined by the potassium-argon method. The Sr^{87}/Sr^{86} and Rb^{87}/Sr^{86} ratios are not altered by melting, hence the strontium isochron age of tektites refers primarily to their parent material. If that was a crystalline rock, then the isochron dates the time when this rock was derived from the earth's mantle, directly or indirectly. If it was a sediment, then the isochron age is an average

of the ages of the primary rocks from which the sediment was derived.

Tektite Fields. There are basically four groups of tektites, undoubtedly formed in four separate events. The largest and youngest tektite field is in the southwest Pacific area, where tektites are found in the southern part of Australia and in Indochina, China, the Philippine Islands, and Indonesia. Australasian tektites differ slightly in physical and chemical properties from area to area; they are uniformly dark brown in transmitted light, and their ages, measured by the potassium-argon and fission-track methods, are about 700,000 years. The Australasian field is by far the largest known tektite field. It is so large, when its possible extension into the Indian and Pacific oceans is taken into account, that geographic arguments for a terrestrial origin of tektites hardly apply to it, as we shall see.

The next older tektites are found in the Ivory Coast Republic. They occur in a relatively unexplored region and are rare. Both potassium-argon and fission-track dating methods give their age as about 1.5 million years. They are also dark brown.

Moldavites, the Czechoslovakian tektites named after the Moldau (the German name for the river Vltava), are next in age. They occur in a small area (about 50 kilometers long) in southern Bohemia and in an even smaller district in southern Moravia. Again, there are slight differences in color and chemical composition. Bohemian moldavites are light green and Moravian ones are olive green or brownish, but both the potassium-argon and the fission-track dating methods yield ages close to 14.8 million years for all of them. The extent of the moldavite fields is better known than the extent of any other tektite area, and a wealth of geologic detail is available.

The oldest tektites are in America, in east-central Texas and south-central Georgia. The Texas tektites (called bediasites after the Bedias or Bidai Indians) are generally brown, and the Georgia tektites are greenish and lighter in color, but ages of about 34 million years have been obtained for all of them. A single tektite was found on Martha's Vineyard in Massachusetts, but this solitary stone is indistinguishable from Georgia tektites and of exactly the same age. One cannot ignore the implication that it was brought to the island by man. The geology of Martha's Vineyard has been studied meticulously, and the area has been combed in search of another tektite, without success.

Geology. Tektites are always found on the surface or in sediments much younger than the measured age of the tektite glass. I am not aware of any valid report of a tektite's having been found in sediments of the same age. Bediasites are found in young gravels on the surface of the Jackson group of formations, usually considered to be of Late Eocene age. In Grimes County, Texas, they are found along the middle and lower parts of the Jackson group, in Fayette County they occur along the upper part of the group, and elsewhere they lie in between. In view of the rarity of tektite-making events in general and the uniformity of bediasites in particular, one could hardly assume that more than one bediasite shower had occurred. The area now underlain by the Jackson group has undergone extensive uplift and erosion in post-Jackson time, as well as some warping, as shown by the relatively high dips of the Early Pleistocene Citronelle formation. Thus it appears probable that bediasites now found on the surface of the Jackson group have been moved by water.

Bediasites are now weathering out of the Jackson formations. If one accepts the view that the Jackson group belongs to the Late Eocene (about 40 to 45 million years ago), then one says, in effect, that Jackson time had ended more than 5 million years before the bediasites fell. That time interval is too large to be ascribed to errors in the age determination for the bediasites or to inadequacies of the Cenozoic time scale. Either Jackson rocks were exposed at the time of the bediasite fall, or else Jackson time extended well into

the Oligocene.

Georgia tektites are exceedingly rare. They are found on the surface of young (Pliocene-to-Pleistocene) gravels that unconformably overlie Eocene, Oligocene, and Miocene rocks. They could have been reworked from any of them.

Moldavites had been thought to be Middle Miocene in age long before their age was measured by the potassium-argon method. When this method gave an age of 14.8 million years, the result was hailed as continuing the stratigraphic correlation. It was even suggested that moldavites could be used as a tie point for the Helvetian stage in the Cenozoic time scale. Detailed geologic survey of the Moravian moldavite field, together with a study of the distribution of unusual and characteristic minerals of restricted provenance in the moldavite gravels, has shown that the earlier stratigraphic correlation is invalid. Moldavite gravels are all very young, Late Pliocene or younger. All known moldavites have been transported by water, even though the distances cannot have been very great.

Ivory Coast tektites are found in recent gravels on an ancient (2000-million-years old) crystalline basement. Australasian tektites also occur on the surface or in strata generally younger than the tektites themselves, but occasionally there is room for doubt in correlating Pleistocene sediments. Hence the argument from stratigraphy carries less weight for these fields than for the older tektite fields.

The Age Paradox. It should not be surprising that tektites are not found where they landed. They are, first of all, geologically rare, even in places where they are most "abundant." In the tektite areas outside Asia it takes a trained man hours to find one.

Even in the Australasian field there are only a few places where tektites are sufficiently numerous to be picked up by the handful.

Being in the size range of gravel, tektites are readily concentrated by running water, especially by the intermittent water of streams in flood. Thus it is obvious why tektites occur in gravels. Furthermore, there is a good evidence that tektites dissolve rapidly in pelitic sediments, especially where the pH is high. The Besednice brick pit occurrence in Bohemia is a good example. The tektites found in the white calcareous clay there are often corroded to mere slivers, yet the clay is quite young and the tektites were probably washed into it. There is no evidence that they fell there.

Hence the supposed paradox of stratigraphic versus radiometric age for tektites seems to be largely imaginary. A tektite is much more likely to have been transported than to lie where it fell. An analogy is the common occurrence of placer gold in stream gravels as opposed to the rarity of "mother lodes" upstream.

The Flight. It is an established fact that tektites fell from the sky. Aerodynamic ablation experiments with tektite glass have gone a long way toward explaining how tektites entered the earth's atmosphere and how they interacted with it. Comparison of synthetically produced ablation forms with the morphology of some well-preserved australites has shown that australites entered the atmosphere at velocities around 10 kilometers per second, and at low angles. Strictly speaking, these results apply only to Australasian tektites, but it has been shown that at least one bediasite and one moldavite also have the flattening that is characteristic of aerodynamic ablation, and one may accept the conclusion that the entry of the less-well-preserved groups of tektites was not very different from the flight of the australites.

But what happened before the tektites entered the atmosphere? The lack of any evidence of cosmic-ray interaction with the tektite glass shows that tektites were not long in space. They could not have come from far away,

astronomically speaking. An object in the mass range of even the largest tektites will be slowed down to a halt after only a few kilometers' flight in air at atmospheric pressure, no matter how great its initial velocity may have been. Thus we are left with two alternatives. If tektites originated on earth, then they have to fly up through an atmosphere that either moved along with them or was temporarily greatly rarefied, presumably by the event that produced the tektites. Alternatively, the tektites could have come from outside the earth's atmosphere, presumably from the moon.

Possibility of a Lunar Origin. There is much that motivates theorizing that tektites came from the moon. Both the composition and the morphology of tektites could be more easily understood if one could assume that the glass was made in a vacuum. Some tektites have bubbles in them, and many of these bubbles preserve a more or less high vacuum. Tektite glass contains an extremely small amount of water, 10 to 100 times less than man-made glass and 1000 times less than obsidian. The spherical and drop shapes of well-preserved tektites indicate some kind of splash of the molten glass and an absence of any strong forces acting on the still-molten particles. Solidification of molten tektite requires from a fraction of a minute to a few minutes, depending largely on its size. During this interval, surface tension seems to have been the dominant force in the shaping of the tektites. These processes can be most readily imagined as occurring in a vacuum. The lunar vacuum would seem to be ready-made for such purposes.

Furthermore, if it could be assumed that tektites are thermally altered samples of the lunar surface, then it would follow that the moon has a highly siliceous crust, with all the attendant implications of internal melting, magmatic differentiation, and an internal structure analogous to that of the earth. The tektite evidence then could be used to sweep aside the alternative hypothesis of a cold undifferentiated moon composed essentially of material similar to stony meteorites. A whole class of hypotheses concerning the origin and early history of the earth then could be dismissed.

One fatal objection has long stood in the way of the lunar origin hypothesis: the lack of any focusing mechanism that would keep the hypothetical tektite swarm together on its long journey from the moon. Only the Australasian tektite field is large enough to be attributable to a fall from an extraterrestrial source, and even there one would have to postulate very little mixing within the tektite swarm en route in order to account for the small but real differences observed in Australasian tektites from place to place.

No mechanism is known that would permit transportation of ejecta from some lunar crater into a target area as small as the tektite fields in Bohemia and Moravia or on the Ivory Coast. The various proposed mechanisms involving intermediate parent bodies also would produce strewn fields much too large to fit the facts. Theoretical analysis of the phenomena following the impact of a large body on the earth indicates that tektites could be formed in such an event. A body such as a comet with a geocentric velocity of several tens of kilometers per second, a density of the order of 0.1 gram per cubic centimeter, and a mass greater than about 5×10^{27} grams, colliding with the earth, would have sufficient energy to blow a momentary "bubble" in the earth's atmosphere and thus produce, for a moment, an environment suitable for the production and ejection of tektites from a terrestrial crater.

Tektites and Craters. The proposal that moldavites are associated with the crater called Nordlinger Ries, in south-central Germany, was made even before it was known that impact glass from the Ries had the same age as the moldavites, which are found roughly 300 kilometers to the east. There were uncertainties about the validity of the first age measurements because of difficulties in completely extracting the radiogenic argon from the viscous tektite

melt, but these technical problems have been resolved, and the age measured by the potassium-argon method has now been confirmed by the altogether independent method of fission-track counting. Within the limits of experimental error, the age of the moldavites and of the crater has been established, by these two independent methods, as 14.8 million years.

The glass in the debris around the Ries crater and the moldavites are of the same age, but their chemical compositions are different. The crater glass is chemically similar to granitic gneiss. Such gneisses are exposed in the Black Forest, a little more than 100 kilometers west of the Ries, and externally similar but severely shocked and altered rock fragments are common in the crater debris. The moldavites, like all tektites, have chemical and isotopic compositions reminiscent of weathered crystalline rocks or the sediments derived from them. In the Ries area, the crystalline basement rocks are overlain by sediments about 500 meters thick. The crater glass and the moldavites could not have come from the same melt but could have been produced by the melting of different rocks during separate phases of the same explosive event.

Another tektite field has a crater nearby. The Ivory Coast tektite area lies roughly 300 kilometers west of Lake Bosumtwi (in Ghana), an undoubted impact crater. Here again the two dating methods give the same result for glass from the impact crater and for the tektite glass—about 1.3 million years. Again, there are some uncertainties about the results, but in this case the uncertainties stem mostly from the obvious fact that an age of 1.3 million years is more difficult to measure than one of 15 million years. As repeated measurements are made, the experimental error is reduced and it becomes clearer and clearer that Lake Bosumtwi and the Ivory Coast tektites were formed at the same time.

The American tektites are not clearly associated with any known impact structure. The Gulf coastal plain region is geologically a poor place to look for an Oligocene crater. The geologic history of the coastal region makes for a vanishingly small probability that any trace of such a crater could be seen there today, had one existed. Further northward, the Kilmichael, Mississippi, structure is large enough and possibly old enough to be considered a possible source of bediasites and Georgia tektites, but it is a difficult one to study. For glass from the Clearwater Lake crater in northern Quebec, the fission-track dating method yields an age of 33.5 ± 4.5 million years, roughly in agreement with the age of the American tektites. This age has not been confirmed by potassium-argon dating. The rocks in the vicinity of Clearwater Lake are very ancient, and American tektites could not have been made from them. The strange glass found in great quantity in the Sand Sea of the Libyan Desert also has a similar age, but it is difficult to imagine what physical connection this glass could have with American tektites.

The size and geography of the Australasian tektite fields strain the imagination in considering a possible association of tektites and craters. The tektites might have come from more than one crater, and hypothetical locations in Antarctica and Indochina have been proposed. The craters would not have formed in the deep sea, but might have formed in the large areas of shallow water. Of the several known dry-land craters in Australasia, none seems to fit.

The Place. Ages yielded by the potassium-argon and fission-track methods link tektites with craters in terms of time but not necessarily in terms of place. The strontium isochron method, however, has the potential for showing where tektites were made.

Whatever the exact process of tektite formation may have been, it could not alter the average $\text{Sr}^{87}/\text{Sr}^{86}$ ratio of the material, and it could only slightly reduce the $\text{Rb}^{87}/\text{Sr}^{86}$ ratio by fractional volatilization of the silicates. Hence

ERM-004 METEORITES AND TEKTITES

it is possible to make age determinations on tektites by the whole-rock strontium method. When plotted on an isochron diagram, the ages obtained in this way for American, Australasian, and Czechoslovakian tektites all fall roughly on the same line with a zero intercept (the initial Sr^*/Vsr^* ratio) of about 0.705. The slope of the line corresponds to an age of about 400 million years. If allowance were made for a rubidium loss of, say, 25 percent, the age would be correspondingly lower, or roughly 300 million years.

This curious agreement for the three groups of tektites could be interpreted in two entirely different ways. Either (i) these three kinds of tektites were formed from a common source material now 300 to 400 million years old, or (ii), in the case of the moldavites, this age would reflect the 300-million-year age of crystalline rocks of the German crystalline basement north of the Alps but the apparent agreement of the American and Australasian tektite isochrons with the moldavite isochron would be, for the moment, unexplained.

For some time, the first interpretation seemed the more likely. It would favor the hypothesis of an extraterrestrial origin of tektites, in view of the difficulty of explaining how rocks at three regions on earth, "picked" effectively at random by the impacting bodies, could have the same strontium isochron age.

As it turns out, however, the second interpretation is probably correct. The crucial argument comes from recent age measurements, by the whole-rock strontium isochron technique, for the Ivory Coast tektites and for a suite of rocks from the vicinity of Lake Bosumtwi. The lake is located in a region of metasedimentary and granitic rocks with hardly any sedimentary cover. The rocks give a clearcut isochron with a slope equivalent to 2000 million years, and both the Ivory Coast tektite glass and the impact glass from Lake Bosumtwi fall convincingly on the same isochron, or a little to the left of it, as would be expected had there been a slight loss of rubidium. There can be little doubt that Ivory Coast tektites were made from rocks 2000 million years old, and that such rocks once lay on the spot now covered by Lake Bosumtwi.

Origin of Tektites. The accumulating geochronologic evidence indicates more and more convincingly that tektites were formed from terrestrial rocks in large meteoritic impacts on the earth. Ivory Coast tektites were formed about 1.3 million years ago, simultaneously with the Bosumtwi crater, and from rocks 2000 million years old. The rocks around the crater are of the same age. Moldavites were formed 14.8 million years ago, simultaneously with the Ries crater, and from rocks now roughly 300 million years old. Crystalline rocks throughout Germany north of the Alps are about 300 million years old. North American tektites were formed 35 million years ago, but no crater is known to be associated with them. Their age, as determined by the strontium isochron method, would be compatible with an origin from Appalachian granites, volcanic rock, or sediments derived from them.

Not much can be said about a parent rock for the Australasian tektites, except that it would be roughly 200 to 400 million years old. The principle of simplicity suggests that one might more profitably look for large concealed craters in that vast region than postulate an extraterrestrial origin for the tektites.

ERM-004 TEKTITES AND GEOMAGNETIC REVERSALS

Glass, Billy P., and Heezen, Bruce C. ; Scientific American, 217:33-38, July 1967.

Some interesting tidbits regarding tektites are extracted from this article.

The possibility that magnetic reversals and changes in fossil plankton were associated with an extraterrestrial intrusion was unexpectedly suggested to us as we were studying sediments from the sea bottom off Australia. In these sediments we found tiny spherules, teardrops, dumbbells and other shapes characteristic of the class of glassy meteorites known as tektites. These microtektites, none larger than a millimeter across, closely resemble larger tektites found on land in that part of the world. They were obtained from a layer starting at the bottom with sediments laid down at the time of the last geomagnetic reversal and ending between 30 and 50 centimeters higher. Spurred by this discovery, we found microtektites in core samples of the bottom taken off Australia and Tasmania, in the Philippines area, near Japan and across the Indian Ocean almost all the way to Capetown. The litter of tektites turned out to cover an area 6,000 by 4,000 miles in extent from Tasmania to well north of the Philippines and from the East Indies to the east coast of Africa.

The fact that the microtektites were all laid down in sediments dated to the time of the last geomagnetic reversal immediately points to a common cause, possibly an encounter between the earth and some massive cosmic body. Naturally one is struck by the fact that the microtektites are similar to the microscopic glassy spherules that fell in the Tunguska Valley forest in the explosion of 1908. Our samplings from the ocean bottom indicate that at least a quarter-billion tons of glassy material was strewn over nearly a tenth of the earth's surface. Undoubtedly a cosmic collision that deposited this amount of material would have caused fantastic destruction of animal and plant life in the area, and it could have raised tidal waves that swept over shores throughout the world, (p. 34)

The Far Eastern tektites occur in at least three forms. Those in one group, found mainly in Australia, have the shape of buttons; they look as if they had been originally molten, then had cooled and finally were partly remelted and eroded by the air as they fell through the atmosphere. Those in a second group, found all over Southeast Asia, are streamlined forms—teardrops, rods, dumbbells, ellipsoids and saucers—that apparently were not aerodynamic ally eroded after they had cooled. Those in a third group, found in Thailand, are irregular pieces of broken glass that show little sign of remelting.

From these facts it has been deduced that when the original body entered the atmosphere it was heated to an immense fireball and may have broken up into two or three (or more) separate bodies. One of these fragments may have exploded in the outer reaches of the atmosphere, so that its glassy debris was first cooled and then was reheated in its passage through the lower atmosphere, producing aerodynamically eroded tektites of the kind found in Australia. If a second major fragment had exploded closer to the ground that might account for the uneroded shapes of the tektites that were not remelted (presumably because this debris traveled only a short distance through the atmosphere). The broken pieces found in Thailand may be the debris of a fragment that exploded so close to the ground that its pieces were not melted smooth by friction with the air. On the slopes of Mount Darwin in Tasmania there are bits of glass resembling tektites, that may have been scattered over the ground by a small segment of the cosmic body that hit the ground, (pp. 35-36)

ERM-005 METEORITES AND TEKTITES

ERM-005 AUSTRALITE ANALYSES

Anonymous; Nature, 228:1259-1260, December 26, 1970.

The origin of tektites is as obscure as ever. So, in the meantime, work continues on individual samples and groups of samples in an attempt to determine how many different tektite falls there have been and how many different mineralogical types exist. The ultimate hope is that from detailed chemical comparisons some unifying property will emerge to permit an unambiguous interpretation of tektite origin.

That many more hard data are required before even simple relationships can be defined properly is evident from, for example, the problems which have arisen in connexion with the Australian tektite field. The microtektites found in deep sea sediments close to the tektite strewn fields of Australasia and the Ivory Coast apparently fall into two distinct chemical groups—the so-called "bottle green microtektites" which have low silica and high magnesium contents, and the so-called "normal microtektites", the chemistry of which is very similar to that of the Australasian tektites, especially in that the silica contents are high. It is debatable, however, whether there really are two distinct types of microtektite. It is sufficient to say that the range of microtektite compositions is apparently wider than the range of tektite compositions. In particular, there is a lack of reports of high magnesium tektites, the continental equivalent of the deep sea bottle green microtektites.

This lack of symmetry has led some people to question the identification of the Australasian microtektites. Other workers, on the other hand, believe that the absence of high magnesium tektites is more apparent than real, the problem being merely one of unrepresentative sampling. Moreover, and for a similar reason, the compositional range of even the normal tektites may not be as restricted as it has hitherto appeared. Glass, for example, has been carrying out detailed electron microprobe analyses of a single flanged australite (Australian tektite) and has found a remarkably wide range of composition within the one sample (Earth Planet. Sci. Lett., 9, 240; 1970). In particular, the silica content varies from 59 per cent to 85 per cent, which easily encompasses the 59 per cent to 76 per cent range of previously analysed normal microtektites. Furthermore, it compares with the previously reported range of 69 per cent to 79 per cent silica for twenty-three australite analyses. The point is that if a single australite can vary to this extent, similar analyses of other australites could easily result in a wider silica range which would encompass all microtektites whether normal or bottle green.

Thus, contrary to the impression given by previous limited data, Australasian tektites probably have a wide range of compositions. If this is the case, there is then no reason why the tektites and adjacent microtektites should not have had a common origin. Such a conclusion has always had strong circumstantial support but it has, until now, seemed to contradict the evidence from detailed analyses.

That some rocks have musical properties is not so surprising. What is unusual is that "fields" of ringing rocks exist and that they are associated with tales of witchcraft, sensory disorientation, biological effects, and ancient ruins. Here, then, are some contrasting reports about these strange rocks, their properties, and their associations. Note that there are geological similarities between the fields of ringing rocks and the so-called periglacial deposits described in subsection ESP.

ERR-001 ROCK MUSIC

Gibbons, John, and Schlossman, Steven; Natural History, 79:36-41, December 1970.

On a June day in 1890, Dr. J. J. Ott played several musical selections for the Buckwampum Historical Society in Bucks County, Pennsylvania. He was accompanied by a brass band, but, in the words of one who was there, "the clear, bell-like tones" he was playing "could be heard above the notes of the horns." What made the concert different was that Dr. Ott was making music by hitting boulders with a hammer.

Dr. Ott had put together an octave of ringing rocks from a boulder field in Bridgeton, one of many dotting eastern Pennsylvania and western New Jersey. The peculiar ability of the rocks in some of the fields to ring like a bell had been known long before, but not until 1965 was a serious attempt made to find out why.

Local myths about the boulder fields abound to this day. Little is known about the Indians' opinions, but many early settlers apparently attributed the boulder accumulations to the aborigines themselves. A vague picture of the fields as ceremonial sites built by the Indians runs through many accounts. Nearly all the explanations, in fact, call upon man or some supernatural force for the genesis of the fields; natural origins are rejected altogether. Other explanations invoke witchcraft, arguing that the fields are either the site of a great curse or are areas possessed by witches. The fields have been called the ruins of ancient civilizations, the landing sites of spacecraft from alien planets, and almost anything else that comes to mind. One local maintained that the WPA piled the rocks in a "make-work" effort.

The common thread through most of the region's mythology appears to be a rejection of natural origins for the fields. The failure of science, through some sixty years of intermittent investigation, to provide any better answers must have helped to confirm that idea. Although the fields may have been visited by naturalists long before, the first comprehensive description was not published until 1909.

The ringing rocks fields are not very different from the other boulder fields in the area. Irregular clearings of ten to fifteen acres in the predominantly hardwood forest, the fields are floored by loosely piled boulders varying in size from one to fifteen feet in diameter. The boulders are made up of a dark igneous rock called diabase that is about 180 million years old. There is no soil between the boulders in the field, and they lie on a sloping bedrock surface of the same rock type. Some worts and lichens are the only plants to be found there. The absence of soil to retain rainfall makes the presence of rooted plants impossible. The microclimate of the area has been aptly described as desertlike.

The boulders themselves are usually flat, and their exposed surfaces are often stained reddish by iron oxides. Weathering has sculptured the upper surfaces into a pitted and grooved pattern. The surrounding forest floor contains boulders similar in size and composition to those in the boulder fields. Out-

side the fields, however, the boulders do not ring, have no reddish stain, and display a peculiar "crazed," or cracked, pattern on their surfaces. One of the persistent observations about the boulders is that they cease to ring if they are removed from the fields.

B. F. Fackenthal published the first scholarly work on the ringing rocks (1909 and 1919). Fackenthal was a naturalist of the breed responsible for much of the early description and exploration of this country. A natural scientist of broad interest and great curiosity, his description of the ringing rocks fields is an interesting and wonderfully informative work. In the 1919 volume of the Bucks County Historical Society Proceedings, he wrote about the geologic setting of the area, and about the then-current explanations of the phenomenon. Venturing a guess of his own about the ringing phenomenon, he said-

"The ringing properties are doubtless due to the texture of the diabase of which they are composed, but why some should respond with a ring and others lying alongside are non-resonant, does not to my mind fully appear. They were doubtless cooled or annealed differently and therefore the crystalization may have been different."

Little more was written about ringing rocks for the next forty-five years, but boulder fields in general were studied enough to be considered a well-understood phenomenon.

Boulder fields of the kind found in the Bucks County area are not particularly uncommon throughout the temperate and arctic regions of the world. Under climatic conditions that feature severe temperature variation above and below freezing, along with enough rain or snowfall to keep the ground wet, frost action can easily produce such boulder fields, or felsenmeer (literally "stone seas"), as they are called in Europe. Water soaking into the bedrock surface expands upon freezing and breaks up that surface. Frost heave, the movements produced in soil by freezing and thawing, tends to move the boulders toward the surface. If the climate is severe enough to prevent plant cover from developing, the soil may eventually be flushed away by summer rains. The result is a boulder-covered bedrock surface with little or no soil.

Huge expanses of boulder-carpeted terrain may be seen today above timberline in most mountainous regions. These felsenmeer are more or less permanent features in those regions of high altitude or high latitude having rigorous climates. How, then, can they be related to the temperate, humid climate of the middle Atlantic region? The answer lies in the history of the last Ice Age. Although the glaciers that last retreated from the area about 12,000 years ago never extended to the actual site of the ringing rocks fields, their presence profoundly affected the area's climate. The nearest ice masses are thought to have occurred only about twenty miles northwest of the site. This places the boulder fields well within the range of periglacial, or near glacial, climatic effects. The areas marginal to the glaciers experienced rigorous climates quite analogous to high alpine climates.

G. Gordon Connalley, a glacial geologist, proposes that all of the region's hillslopes were shattered by severe frost action during glaciation. After the glaciers retreated and the climate returned to its present state, the boulder seas were gradually reclaimed by the forests. The fields still in existence are in last remnants of once extensive felsenmeer. Even these remnants are being encroached upon by the forest. The trees near the edges of the field are younger than the rest of the surrounding forest, and in some places the boundaries are blurred by the advance of shrubs and vines into the fields.

In general, none of these ideas about the origin of boulder fields is new. Most geologists have long agreed that most fields originated in the way just outlined. The trick is to explain why the ringing boulders ring.

In 1965 Richard Faas, an oceanographer and geologist from nearby Lafay-

ette College, and John Flocks, a student, took up the problem. Faas and Flocks were interested in problems of sound travel in rocks. This interest arose from Faas's studies of sound travel in ocean bottom sediments.

Faas and Flocks demonstrated that the audible tone produced by a blow on a ringing boulder was the product of interference between several subaudible resonant frequencies. That is, when struck, the boulder vibrates at several frequencies. None of these frequencies is audible, but the sum of the interfering and interacting frequencies produces a tone that can be heard by the human ear. The subaudible vibrations have unusual frequencies (cycles per second) and attenuation (duration) for rock materials. Faas and Flocks also pointed out that the tones produced showed some correlation with boulder size.

We became interested in the problem through Faas and several teaching trips to the fields. Our field observations, added to Faas's sonic data, led us to a tentative hypothesis about the ringing boulders and eventually to a systematic study. The ringing boulders often spall (flat chips break off from the surface) when tapped lightly with a hammer. These spalls are surprisingly energetic, sometimes flying past one's ear with a humming sound. If a ringing boulder, which is very tough, is broken apart with a sledge hammer, it soon stops ringing altogether. Such breaks produce a peculiar surface pattern often seen in metals that have broken under large internal stresses. The boulders are unusually absorbent when wet. The outer inch or so of most of the boulders is noticeably altered in color and texture by weathering, and that altered zone soaks up water at a surprising rate.

Formation of a workable hypothesis, one that would form a solid foundation for research, is a critical matter in such a project. If the hypothesis is carefully thought out, it has an organizing effect on the whole effort. It is necessary to begin with a question—in this case Why do the ringing rocks ring? The next step is to assemble all available information. This information can then be used to weed out the most likely answer or answers. Once a test hypothesis has been chosen, it is important to state it in the simplest and most concise terms possible. When that is done the questions needed to test the hypothesis become clear almost automatically. If the questions are answered in the affirmative, that is, if the correct hypothesis was chosen, then interpretation of the impact of the hypothesis on other, related questions is the final step.

In the case of the ringing rocks the process went something like this. Question: Why do the boulders ring? Information: The rocks were very energetic (spalling fracture type); they resonated at a frequency different from the "natural" frequency; and there was something unusual about the fields' dry and exposed environment that seemed to produce or at least localize the abnormal resonance. Our search for a hypothesis seemed to lead back each time to one focus: How can the resonant frequency of rock be altered by a natural process?

All materials have what may be called a natural resonant frequency. That is, because of its atomic structure any material has one vibration frequency at which it resonates, or responds harmonically, to its own vibration. Natural resonance is a well-defined concept that has been thoroughly studied by metallurgists and engineers. The natural resonance of crystalline substances, such as minerals, depends primarily upon the strength of the atomic bonds and upon the atomic spacing.

The most feasible way of changing the resonant frequency of a material is to subject it to an elastic strain. Elastic strains are impermanent changes in the shape or size of a body. That is, if a body is elastically strained and the stress is removed, the body returns to its original shape or size. Elastic strain involves no breaking or rearranging of atomic bonds. Rather, the material changes shape by what can be thought of as stretching the bonds. When the stress is removed, the bonds rebound, returning the atomic structure to its

original position. While the bonds are stretched, however, the resonant frequency of the material is changed because the atomic spacing is altered. A good example of this principle is the old musical saw act from vaudeville days. The musician changed the tone of the saw by bending (elastically straining) the saw while he stroked it with a violin bow.

Now we can modify our original question: Why do the ringing rocks ring? If elastic strain is the most easily visualized means of changing the resonant frequency of a body, the question can be rewritten: Do the ringing rocks ring because they are somehow under stress?

We decided the best way to find out would be to dissect the rocks and see if they showed signs of stress. This technique assumes that any body subject to stress over a long period of time will reach equilibrium, a balanced state, if it does not break. Ice in a glass bottle provides a familiar analogy. As the ice expands, tension increases in the glass. The forces are balanced—until the glass breaks. Before the glass breaks, it is possible to measure the stresses in the ice-bottle system indirectly. Melting the ice removes the stress; then the return of the bottle to its original size and shape can be measured. Because the force needed to "stretch" glass (this is known as its elastic constant) is known, it is easy to compute how much stress was required to stretch the glass by the measured amount. Rocks are more complicated than ice in bottles because the balanced forces exist in the same object. But the stress regions tend to lie parallel to the object's surfaces when equilibrium is complete. So by slicing off sections parallel to the surface, we can measure the change as the core returns to its original size and shape. We also have to know the elastic constant of the material involved, but this is either available in published reports or can be easily measured in the laboratory. Then we can say how much stress was present in the rock.

To use this technique we sawed the ends and sides from boulders, leaving only central cores. We carefully measured the cores many times over a long period of time to determine whether any change of dimensions took place. The first ringing rock core we measured was almost eleven inches long. A relaxation (contraction) of almost 1/500 of an inch was observed.

That measurement exceeded our wildest estimates and led us to believe that the technique of measurement was introducing a large amount of error into the data. Therefore we decided to use electronic measurement with foil strain gauges. These tiny strips of metal and plastic can measure extremely fine changes of shape on a surface when coupled with the proper electrical receptors, amplifiers, and strip-chart recorders. They have the additional advantage of constantly recording the change in shape of the body as time passes, producing a new kind of information, as well as greater accuracy and precision.

The sensitivity of foil strain gauges is fantastic. While testing and calibrating the equipment we glued a strain gauge to an old core of very hard diabase, about one and a half inches on a side and nine inches long. Just for fun, one of us placed the core over his knee and tried to bend it. The recorder dutifully recorded 1/100,000 of an inch strain.

Foil strain gauges showed that the cores from ringing boulders relaxed an average of approximately 1/10,000 of an inch per inch of specimen length. Nonringing boulders from outside the fields showed no relaxation. In most cases total relaxation required between seventy and eighty hours. Early relaxation was rapid, followed by a long period of gradual change of specimen shape. Occasionally, the gradual tapering off was interrupted by sharp fluctuations; in two cases these could be correlated with the formation of visible fractures.

Core relaxation as time passed was plotted as a curve on a strip-chart recorder. The various forces that can change the shape of a body tend to pro-

duce curves that have characteristic shapes, or "fingerprints." The curves from the ringing boulders compared well with curves for a type of relaxation metallurgists call after-working, or anelastic strain. In the field of rock mechanics the same phenomenon is called recoverable creep.

Normally the strain magnitudes measured indicate the result of tremendous stresses. By using the experimentally determined elastic constants for diabase, published by Francis Birch, and the relaxation figures that we obtained, we could compute theoretical values for the stresses stored in the rock. For some rocks these values were as high as 15,000 pounds per square inch. Such large stress values are particularly perplexing in boulders lying in an open field acted upon by no observable external forces.

Creep, or anelastic behavior, is a particularly logical explanation for this apparent paradox. It can produce fairly large strains at relatively low stresses, with the important qualification that the stress be applied over a long period of time. Therefore, the large stresses seemingly indicated by the computation based on Birch's short-term constants are not particularly relevant. The strains observed seem to be the result of stresses applied over very long periods of time.

The origin of the stresses was determined by more conventional geologic techniques. We prepared thin sections from several areas within each boulder and examined them under the petrographic microscope. The outer "skin" of the boulders is, as already mentioned, quite permeable to water. Water combines chemically with minerals and changes them in the process called chemical weathering. New minerals, usually clays, are often produced when the original minerals are broken down by water.

Microscopic examination showed that chemical weathering had in some cases advanced two or three inches into the boulders. The most chemically susceptible mineral in diabase is pyroxene. The pyroxenes in the diabase were completely altered to a type of clay known as montmorillonite. Alteration of pyroxenes to clay diminished as distance from the surface became greater.

The source of the stresses in the boulders was clear at once. The change from pyroxene to montmorillonite produces a volume change. If a given volume of pyroxene is weathered to montmorillonite, the montmorillonite occupies more space than the original pyroxene. The expansion of many grains of pyroxene during weathering produces an expansion of the outer shell of the boulders and a corresponding tension in the core. The strain resulting from the tension raises the resonant frequency from its natural value to that observed in the ringing rocks.

Stresses caused by weathering exist in many rock types. In most, the stresses cause a surface sloughing known as exfoliation. The combination of unusual strength and slow production of stress allows the diabase to accumulate stresses of great enough magnitude to produce the ringing effect.

The arguments presented up to this point are entirely internal: they all come from a study of the boulders. Now we needed some external confirmation to make the argument tight. Relaxed cores, which no longer rang, were fitted with steel grips. When restressed in an engineering tensile tester to 10,000 pounds per square inch, the cores rang clearly. With this reasonably independent confirmation of the association between strain and ringing, we were satisfied that our original hypothesis was confirmed.

We also wanted to know the role of the special boulder-field environment in producing the ringing effect. Apparently the answer lies in a very delicate balance between weathering rate and rock strength. The boulders in the fields are not buried in soil or shaded by overhanging trees. They are wet only for a short period following a rain or snowfall. This makes the chemical alteration of the minerals and the stresses produced by those alterations accumulate

at a very slow rate. Frost action, the breaking of rock by expanding ice, is probably also minimized by the short time water stays in the system. Long periods of time for the establishment of a state of stress equilibrium are thus provided.

Those boulders outside the fields exist in a different environment: they are shaded and usually lie on or in water-retaining soil and forest litter. Weathering and frost action proceed much more quickly. Time for adjustment of the stresses in the rock to an equilibrium state is insufficient, and the boulders "crack up."

This conclusion explains why boulders removed from the field stop ringing. If left outside in a rock garden or other shaded spot the boulders are soon over-stressed and break up. Ringing rocks kept dry in geologic collections continue to ring indefinitely.

The delicacy of environmental controls on the ringing effect can be illustrated by examining the edges of the boulder fields: the zone separating boulders that ring from those that do not is relatively sharp. The boundary usually lies several feet within the field. The position of the boundary was a puzzle until a botanist friend accompanied us to the site one day. His chance comment about the plants growing along the shade line from the bordering trees struck home. The boundary of the ringing boulders area corresponds roughly to the average position of the shade produced by the larger trees about the edges of the field. More shade means less evaporation and thus more moisture retained. Enough apparently, to disrupt the balanced processes that cause the boulders to ring.

We therefore propose that the answer to the ringing rocks lies, not in witchcraft or ancient ruins, but in a very subtle and delicate interaction between earth materials and environment over very long periods of time. These are things that cannot be observed in terms of man's unaided senses. The concept of the immensity of geologic time is peculiar enough to most people. The measurements necessary to detect and measure the data presented here are impossible without complex instruments. Faced with phenomena for which there are no observable causes, it is completely logical that supernatural explanations should be proposed. Such proposals are the product of the same curiosity that has produced all sciences, especially the natural sciences.

The face of the natural sciences has been changing radically over the past few years, and the proposed solution to the ringing rocks problem presented here is a good example of that change. Once, people like B. F. Fackenthal were naturalists. Their approach to problems could be broad and general because the volume of material to be mastered in the natural and physical sciences was relatively small. Then came the "information explosion." It has become impossible for a man to be acquainted with all the knowledge in his own field, much less in many fields at once. The Renaissance man seems to be lost. Workers with narrow specialties are the rule. This situation has led to many scientific impasses. Problems involving natural systems are often simply too broad and complex to be managed by one man's education.

The solution appears to lie in the multidisciplinary approach. The team we put together to solve the mystery of the ringing rocks included three physicists, two engineers, four geologists of varying specialties, two biology students, and one botanist. Once we all got together, those rocks didn't stand a chance.

See a rebuttal of this article in ERR-002.

ERR-002 WHY THE ROCKS RING

Anonymous; Pursuit, 4:38-41, April 1971.

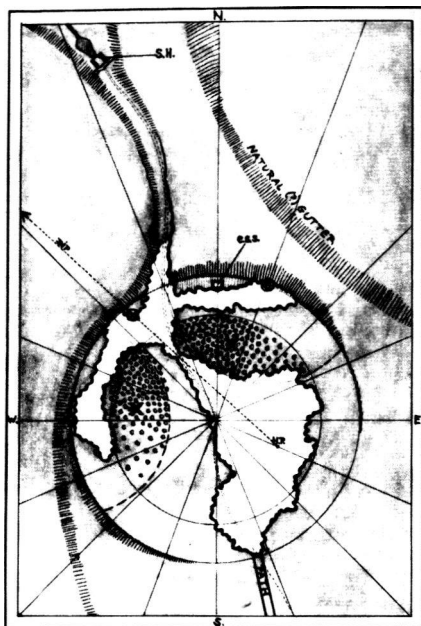
An excellent article appeared in the December issue of Natural History, the popular magazine published by the American Museum of Natural History in New York, entitled "Rock Music", by John Gibbons and Steven Schlossman. This purported to explain why some of the rocks "ring" in the now famous Bucks County rock fields in Pennsylvania. While the reasons they put forward for this phenomenon are doubtless precisely so from the mechanical, mineralogical, and even possibly the geological points of view, their hypothesis, as given in this article and in a lengthier scientific paper published previously, is unfortunately founded in part on some false observations or assumptions. Further, they failed to investigate the biological aspects properly, and especially the botanical. Then there is another matter which they did not take into account, but doubtless because it had not been recorded when they wrote their paper. Let us dispose of this first.

When satisfactory aerial photographs were taken of the rock field at Upper Black Eddy, and proper maps were drawn from them, a number of highly suspicious conformations came to light. This field turned out to be precisely circular when certain features, other than the bare vegetationless area, were taken into account. Further, there is a deep moat, with a high ridge on the inside, going more than two thirds of the way round this area. There is also a double extension of this wall going down a valley to the northwest, ending around a small basin kept fed by a year-round spring. On a subsequent survey of this location, one of our members, a stone mason (and also a keen spelunker) crawled into a small "cave" between the tumbled boulders on the other side of this ridge and discovered two traces of enormous cutstone blocks that were laid horizontally and morticed. From this we can but assume that, at least at this location, somebody did some building in very ancient times. We are urging further controlled professional excavation by the appropriate authorities to ascertain whether the whole moat and its inner ridge might be man-made, and the latter have a cut-stone footing all around it.

This discovery does not, of course, explain the "ringing" properties of some of these rocks and probably has nothing to do with it. The map of this location looks very much like that of a European copperage hill fort, and early settlers might simply have made use of these convenient places where rocks did not have to be dug out of the ground or quarried.

Coming to the rocks themselves, we must point out that in describing their occurrence, Messrs. Gibbons and Schlossman omitted one very pertinent fact. Their statement that "The peculiar ability of the rocks in some of the fields to ring..." should have read: "The peculiar ability of some of the rocks on the fields to ring..." There is a world of difference between these two statements, and this is of the utmost significance. And, pertinent to this are two gross misstatements that they repeat several times. The first is that the rocks cease to ring if removed from the fields—an observation that is contradicted by their further statement that "Ringing rocks kept dry in geologic [sic] collections continue to ring indefinitely". Second, they state that, if left in moist situations in "rock gardens or other shaded spots, the boulders are soon overstressed and break up". They also make several other flat statements that are just plain nonsense, such as that these rocks are usually flat topped, and that, when broken up with a sledgehammer, they soon stop ringing, and so forth.

By actual counts, about 30% of the rocks in these fields ring (though this seems to vary throughout the year), and ringers are found occasionally under



Upper Black Eddy Rock Field, showing a possible ground plan of a neolithic hill fort, based on the conformity of the apparent moat and double dykes, it should be noted that the center of this apparent circle falls exactly upon, or very close to, the assumed junction of the upper group of underground streams. An internal source of water that could not be poisoned was a feature of copper and early bronze - age defensive points.

H. P. High point
S. H. Spring house
C. S. S. Cut stone blocks

....." Underground stream

the trees, but only in those two areas inside the circle, (see map). We have yet to find a boulder that has ceased to ring (and with the same tone) when removed to our HQ, forty miles away; and we brought the first set from Upper Black Eddy in 1961. Further, we have had some of these rocks completely submerged in one of our ponds, lying about under trees, suspended on wires or set in concrete in a damp cellar, on shelves in our laboratory, and even in our house which is exceptionally dry; and they all continue to ring. Also, we have smashed up innumerable boulders of all sizes, and all the parts continue to ring, even down to cut slices three inches by one inch and 1/4 inch thick as always. The explanation for the physical properties of the ringers, as given by Gibbons and Schlossman may be valid to a point; but the basic premises upon which they erected their theory are (to coin a phrase) all wet.

Then again, they appear to have done nothing whatsoever about the petrological aspects of the matter, which causes us to doubt what mineralogical findings they allege. The constitution of the diorite 'family', of which the diabase country rock of these fields is a member, is "a soda-lime or lime-soda feldspar approximating to an andesite in composition, together with hornblende. The possible minerals are oligoclase, andesine, labradorite, hornblende, biotite, augite, enstatite, quartz, apatite, and magnetite" [see Minerals and the Microscope, H. G. Smith, London: Thomas Murby, 1922]. Our member 229, chief technician of a large ceramo-metal products manufacturer ran a considerable number of series of tests of three sets of specimens, identified only by numbers, to wit: (1) ringers, (2) non-ringers from inside

the circle, and (3) non-ringers from outside the circle, some from as far away as a mile. In developing gross samples of glasses by fusion from these, it was found that the melting point of (1) differed markedly from (2) and (3). Much more significant was the fact that different metals—in the form of amorphous globules—appeared in these two groupings. The non-ringers gave what appeared to be copper, the ringers a white metal of very high lustre. We have so far obtained only one report on the analysis of the latter, and this claimed that it was molybdenum!

Turning to the biological aspects, we fear we must be much more critical. We have had the Upper Black Eddy field under surveillance on a fairly regular and seasonal basis for ten years, and we have run a series of laboratory experiments. These will eventually be reported on in full, so suffice it to state now that ringing rocks kept (in fish tanks) alongside non-ringers, and in open pond water (filtered), in well water, and in distilled water, in all cases inhibited both contamination and growth of all kinds, while developing from themselves large patches of pure white fungoid mycelia that, in the absence of fructification, cannot be identified. The absence of both animal and plant life on this field—as diametrically opposed to screes and other bare rock fields in the area—is even more peculiar than it at first appears to a non-biologist. The list of animals is comprised solely of a number of species of spider, two micro-lepidoptera ("mini-moths"), and (so far collected) seven species of Diptera (flies). The last, however, appear all to be of one Family.

It should also be put on record that while neither domestic nor wild-caught animals (both local and imported) on leashes, show any disinclination to cross the rock field, birds seem most reluctant to do so, and may often be observed flying halfway around the circle in order to cross it. We have never found any bird droppings on the field. Turning then to the botanical oddities we must put on record a really most remarkable phenomenon, one that we have never heard of elsewhere—outside a laboratory. This is that a very high percentage of the trees growing in the two areas marked "X" on the map, have what is called onion-bulb trunks, in that their bases immediately above ground are swollen just like a fat onion. Such a condition has been reported in laboratory experiments in which plants were grown in soil containing high concentrations of artificially introduced compounds of (or native) copper. Finally, we should add that trees that either fell onto the edge of the bare rocks, or apparently tried to grow out over it when saplings, perform the most extraordinary horizontal gyrations, usually leading their growing points back under the trees, and all of them develop branches only on the upper side, while these go straight up and then bend back into the shade. This defies all known laws for woody plant growth, and on several scores.

Altogether, while the explanation of the mechanics of the ringing by some of these rocks as given by Gibbons and Schlossman may be perfectly feasible despite so many mistaken premises, it does nothing to explain the incidence of the fields themselves, nor even to explain why only some of the rocks ring. And when it comes to other things not observed by them—such as that there are some larger rocks which, when hit appropriately, give rise to a whole scale; that most of the curious scalloped erosion is on their undersides; that two different ringers when knocked together while suspended on wires produce (invariably, it seems) but one tone, however many different combinations are used; and so on—it is manifest that we have a very long way to go yet before we explain these singular natural phenomena.

ERR-003 RINGING ROCKS

ERR-003 MUSICAL STONES

Nelson, Richard J.; Nature, 8:46, May 15, 1873.

When roaming over the hills and rocks in the neighbourhood of Kendal, which are composed chiefly of mountain limestone, I have often found what we call here "musical stones." They are generally thin flat weather-beaten stones, of different sizes and peculiar shapes, which when struck with a piece of iron or another stone, produce a distinct musical tone, Instead of the dull heavy leaden sound of any ordinary stone. The sound of these stones is, in general, very much alike, but I know gentlemen who possess sets of eight stones which are said to produce, when struck, a distinct octave. Being only an amateur geologist, I am unable to account for this fact, and would be glad if any of your numerous readers would take the trouble to explain to me, through the medium of your columns, the peculiar composition of the stone in question, and the distinct qualifications necessary to form a musical stone.

ERR-004 SOUNDING STONES AT CH'UFU, SHANTUNG

Tingle, Alfred; Nature, 73:222-223, January 4, 1906.

Last July I happened to pass through Ch'ufu, the birth and burial-place of Confucius. In "seeing the sights" of the town I found three very fine examples of "sounding stones," or "stone gongs" as they are sometimes called. These particular examples do not seem to be very well known except by Chinese; none of my foreign acquaintances who have been in Ch'ufu had noticed them. Photo No. 1 shows the tomb of the grandson of Confucius. The cover of the incense dish (on which my servant is resting his hand) is made from stone, but when struck with a stick, or even with the knuckles, it rings as though it were bronze. In fact, my man in the photograph refused to believe that it was anything but painted bronze until I myself assured him to the contrary. Photo No. 2 shows two pillars (marked with crosses) of the balustrade in front of the principal hall of the great Confucian temple at Ch'ufu. Struck at any point with a piece of wood, they give a distinct musical note.

Inside the temple is a large tablet, about 5 x 3 x 1/2 feet, of the same stone. In this case the note produced varies according to the point at which the stone is struck. The stone from which all these bodies is made is a greyish oolitic limestone. I was informed that it came from a quarry at Kwan Ko Shan, about seventeen miles south-east of Ch'ufu. Most of the stone from this place has no musical quality, but from time to time veins of it are found, and when found it is usually abundant. "Stone gongs" of this kind are found in all parts of the country, and some are in the possession of foreigners. So far as I can find out, they all come from this one locality. They have been known for many centuries, and it is recorded that the district from which they come paid its share of a certain special Imperial tax in "sounding stones." I should be pleased if any reader could give the cause of this very remarkable property, and if it is not understood I would gladly give what help I can towards elucidating it. During this journey I was pressed for time, and as my route lay directly east from Ch'ufu I was not able to visit the quarry. Should there be any object in doing so, however, I will take the first opportunity of returning and making any observations that I may be asked to make. Such an opportunity may occur at any time, and, in fact, could be easily made to occur, as the journey would only take four days each way. I am afraid, however, that it might prove very difficult to secure any sample of this stone for transportation to Europe.

Musical sands occur all over the world under various names—whistling sands, sonorous sands, barking sands, etc. No one claims that any deep, dark mystery is involved, but the whole business is rather curious. It is also possible that there is some connection between musical sands and the unexplained hums and musical notes described in section GS in the STRANGE PHENOMENA series.

ERS-001 RESEARCHES ON SONOROUS SAND IN THE PENINSULA OF SINAI

Bolton, H. Carrington; American Association for the Advancement of Science, Proceedings, 38:137-140, 1889.

Abstract. This paper is in continuation of two others on Musical Sand presented jointly with Dr. Alexis A. Julien at the meetings in Minneapolis and Philadelphia. After alluding to a recent lecture by Mr. Cecil Carus Wilson of England on the singing beach at Bournemouth, the speaker proceeded to narrate his own researches in Arabia Petraea. Leaving New York, January 2, 1889, I reached Cairo January 31st, and in March entered the desert of Sinai; the village of Tor which is the starting point for Jebel Nagous Is on the Gulf of Suez, but cannot conveniently be visited by water owing to contrary winds. Jebel Nagous is off the regular caravan routes and is not popularly known, hence has been visited but nine or ten times in eighty years by scientific travellers. About four and one-half hours northwest of Tor Is the long detached mountain known as Jebel Nagous (or Abu Suwelrah). On the steep slopes of this mountain rest several large banks of sand; one of these, which I distinguish by the name Seetzen's Bell Slope, after its discoverer, emits distinct musical sounds whenever the sand slides down the incline either spontaneously or through the agency of man. The mountain consists of massive white sandstone carrying quartz pebbles and veins; it is about three miles long and 1,200 feet high. The huge Bell Slope measures 260 feet across the base, five or six feet across the top and is 390 feet high; It is bounded by nearly vertical walls of sandstone. The yellowish white sand rests on the rocks at the high angle of 31° , is very fine grained, and composed chiefly of quartz and calcareous sandstone. The grains are well rounded to subangular, and silt is notably absent. As the sand reposes at a high angle it possesses a curious mobility which causes it to flow down the Incline like soft pitch or molasses; the sand above the point of disturbance falls into the depression and this depression advances up the slope at the same time. This downward flow takes place spontaneously whenever the sand, forced up the Incline by the violent winds, accumulates in such quantity as to exceed the angle of rest. The movement is accompanied by a strong vibration and by a musical tone resembling the lowest bass note of an organ with a tremolo stop. The larger the bulk of sand moved the louder the sound; it is by no means so sensitive as the sand of so-called singing beaches (which I have described elsewhere), and falls to emit sounds when struck with the hand or clapped together in a bag. The vertical cliffs on either side yield an echo that may magnify and prolong the sounds, which were loud enough to be heard several hundred feet. The peak of Jebel Nagous rises above the Slope to the height of 955 feet above the sea level.

The sand of the Slope is derived partly from disintegration of the rock itself and partly from the more distant plain below, from which violent winds blow it up on to the mountain side.

The Bedouins of the region account for the acoustic phenomenon by attributing it to the Nagous or wooden gong of a subterranean monastery in the heart

of the mountain, and claim the sounds can only be heard at the hours of prayers.

Several other sandbanks presenting a similar appearance to the eye were tested but gave out no musical sounds whatever. Microscopical examination of these sands shows that they contain much slit, which prevents the vibrations necessary to yield the sounds. After careful study, however, of Seetzen's Bell Slope I became convinced that the phenomena could not be unique in the desert as supposed, and I made systematic search for another locality. After testing many sandbanks on the Journey northward to Suez I discovered, April 6th, banks of sonorous sand resting on low cliffs a quarter of a mile long. This new locality is in Wadi Werdan about a day and a half from Suez, by camels, and is on hills called Ojrat Ramadan.

The sand blown from the extensive plains to the north, falls over the southern face and rests at two angles, 31° at the top and 21° or less near the base. Wherever it possesses the mobility before described it emits a distinct musical note on being disturbed. The highest bank measures only sixty feet on the incline, and it is not probable that the sounds can occur spontaneously. Dr. Julien has named the new locality Bolton's Bell Slope, and reports that microscopical examination shows the sand to consist chiefly of quartz grains, and a larger proportion of calcareous sandstone than at Jebel Nagous. The size of the grains of quartz varies from 0.11 to 0.42 mm. and of sandstone 0.11 to 0.34 mm., the average being smaller than that of the sand grains on Jebel Nagous. Like the latter it is very free from silt.

Various hypotheses have been proposed to explain the cause of the sonorous property in certain sands. Sir James Prinsep, Secretary of the Asiatic Society of Calcutta, attributes the sound produced at Jebel Nagous to a "reduplication of impulses setting air in vibration in a focus of echo." Hugh Miller, after his visit to the singing beach at Elgg, interested his friend Sir David Brewster in the problem, and he wrote of "accumulated vibrations of the air when struck by the driven sand, or the accumulated sounds occasioned by the mutual impact of the particles against each other." The sonorousness of the sand at Kauai has been attributed to the cellular character of the coralline material, that of Jebel Nagous to its essentially quartzose nature; that of the Baltic coast of Prussia to the saline crust on the beach (Dr. Berendt); but the researches of Dr. Julien and myself show that the sonorous property is independent of material and of saline waters. Many other explanations have been offered which we can here but briefly name: electricity; effervescence of air between moistened grains; solarization; and reverberation within subterranean cavities. Charles Didler, when travelling in Arabia, heard of the acoustic phenomena at Jebel Nagous, and although he did not visit the place promptly offers to explain it by attributing the sounds to "interior cataracts or a subterranean volcano."

Mr. Carus-Wilson, whose paper we have already noticed, explains the sonorousness of sand on a beach as follows: "The music from sand is simply the result of the rubbing together of the surfaces of millions of perfectly clean grains of quartz free from angularities, roughness or adherent matter in the form of clinging fragments investing the grains, and that these microscopic emissions of sound though individually inaudible, might in combination produce a note sufficiently powerful to be sensible to us." (Lecture of Nov. 2, 1888.)

Without attempting to analyze or criticise the above theories, we forthwith give our own, already read to the New York Academy of Sciences on Oct. 15, 1888.

Dr. Julien and I believe the true cause of sonorousness in the sands of singing beaches and of deserts to be connected with thin pellicles or films of air, or of gases thence derived, deposited and condensed upon the surface of the sand grains during gradual evaporation after wetting by the seas, lakes, or by rains. By virtue of these films the sand grains become separated by elastic

cushions of condensed gases, capable of considerable vibration, and whose thickness we have approximately determined. The extent of the vibration and the volume and pitch of the sound thereby produced, after any quick disturbance of the sand we also find to be largely dependent upon the forms, structures and surfaces of the sand grains, and especially upon their purity or freedom from fine silt or dust.

Though the environment of the sand on beaches and in the desert differs greatly as respects moisture, we believe that the above theory is applicable to both. Statistics of rainfall in the desert are wanting, but the experiences of travellers and my own observations show that rain falls, in the winter months, abundantly in many parts of the peninsula. In the vicinity of Mount Sinai heavy snows and rain are precipitated in December and January, occasionally causing veritable floods in narrow valleys as experienced by Captain Palmer. I noted a two hours' shower in Wadi Felran in March (1889), and I saw raindrop impressions on mudflakes at several points on the coast. Water, therefore, is not wholly lacking to aid in the chemical cleansing of the sand grains, and the powerful winds accomplish the work of sorting and winnowing done by the waves elsewhere. The fineness of the grains at the Bell Slopes makes the displacement of a very large amount of sand necessary for the production of sound, while the coarser particles on the beaches yield a resonance on a smaller provocation.

We have, elsewhere (Proceedings Am. Assoc. Adv. Science, 1883 and 1884) shown that the pitch of the musical notes produced on sea beaches is directly proportional to the mass of sand moved, the greater the mass the lower the tones; on the Bell Slopes in the desert the large mass moved yields a very deep note.

The bell-like sounds of Jebel Nagous are also mentioned in the Series G sourcebooks because geophysical origins have also been proposed.

ERS-002 THE SINGING BEACH OF MANCHESTER, MASS.

Bolton, H. C., and Julien, A. A. ; American Association for the Advancement of Science, Proceedings, 32:251-252, 1883.

Abstract. The authors describe the acoustic phenomena observed by one of them at Manchester-by-the-Sea, Mass., and on the island of Eigg, Hebrides, together with the results of microscopical examination of the sands. The beach at Manchester forms a small crescent about three-quarters of a mile long, and is terminated at each end by bold promontories of granite, rich in feldspar, and intersected by numerous dykes of igneous rocks among which porphyritic dolomite is noticeable. The beach sand resembles at first sight ordinary sea-shore sand, but when struck by the foot, or stroked by the hand, yields a peculiar sound which may be likened to a subdued crushing; the sound is of low intensity and pitch, and is not metallic nor crackling. This phenomenon is confined to that part of the beach lying between water-line and the loose sand above the reach of ordinary high tide. Some parts of the beach emit a louder sound than others. The sounding sand is near the surface only; at the depth of one or two feet the acoustic properties disappear, probably owing to the moisture. Only the dry sand has this property. The sounds occur when walking over the beach, increase when the sand is struck obliquely by the foot, and can be intensified by dragging over it a wooden pole or board. A slight noise is perceptible upon mere stirring

by the hand, or upon plunging one finger Into the sand and suddenly withdrawing It.

Similar beaches occur In various parts of the world. One of us visited the island of Elgg, Hebrides, in July and found the acoustic phenomena quite similar to those of Manchester. The Elgg locality has been described by Its discoverer Hugh Miller. One of the most famous localities in the world is on the island of Kauai, of the Hawaii Islands. There the sounds are said to be so loud as to resemble distant thunder, when any great weight is dragged over it. As elsewhere dampness prevents the sound. The sand is almost wholly calcareous and has been examined by Dr. Blake of San Francisco.

In other places sonorous sand Is associated with high dunes or steep hills; of these the most famous Is Jebel Nakous on the Gulf of Suez, In Arabia Petraea, which has been described by many European travellers. A similar hill exists near Cabul in Afghanistan. The sand of these hills Is silicious. In Churchill Co., Nev., a somewhat similar phenomenon is described, the sound being likened to that produced by telegraph wires when the wind blows through them.

Microscopical examination of the sands from several localities shows them to be unlike In constitution, in form, and in structure. The sand of Manchester is about fifty per cent feldspar, that of Kauai is calcareous, that of Elgg silicious. The latter Is peculiar In containing dark granules of chert (to about three or four per cent of the whole) which has a cellular structure. The quartz is present in various sizes, some rounded and others angular.

To explain the sonorous properties of these sands several theories are considered. That of equality of size of the grains Is rejected. Resonance due to cellular structure probably accounts for the sound in the sands of Kauai and of Elgg, but this structure does not occur in other cases. Effervescence of air between moistened surfaces does not apply to the Manchester sand. Sonorous mineral or rock, such as clinkstone, Is not present. There Is no evidence of electrical phenomena being concerned. The hypothesis adopted is based upon the structure of the sand which, instead of being composed of the usual rounded particles, is made up of grains with flat and angular surfaces. In the Manchester sand, the plane surface of feldspar is apparent in many of the grains. Probably a certain proportion of quartz and feldspar grains is adapted to give the sound, while less or more of either component would fail of the result.

It is concluded that different conditions are concerned in the production of the sound in different localities; as, for example, cellular structure, intermixture of grains having cleavage planes, parallel arrangement, slight cementation of the grains, etc.

The paper, which Is to be regarded as a preliminary notice, ends with a table showing the physical structure of the sands from many localities. The authors add an urgent request for the contribution of similar facts and additional material from other places at which the phenomena may be observed.

ERS-003 MUSICAL SAND, ITS WIDE DISTRIBUTION AND PROPERTIES

Bolton, H. Carrington, and Julien, Alexis A.; American Association for the Advancement of Science, Proceedings, 33:408-413, 1884.

Abstract. At the Minneapolis meeting of this Association we gave some account of the so-called "singing beach" at Manchester-by-the-Sea, Mass., and of the occurrence of sonorous sand at Elgg and other foreign localities. During

the twelve months which have elapsed since our joint paper we have not ceased to pursue our Investigations, and although these are by no means completed we here present a summary of the more Important results.

By means of extensive correspondence we have established the fact that sonorous sand instead of being a rarity is of very common occurrence and widely distributed. Through the courtesy of Mr. Sumner I. Kimball, General Superintendent of the U. S. Life Saving Service, circulars were sent to all the keepers of life-saving stations throughout the United States, making inquiries as to the occurrence of sonorous sand, and soliciting samples. Replies have been received from about 85 keepers, 65 of whom report affirmatively in letters of much Interest. It Is of course Impossible to enumerate them in this abstract, much less quote them. One of us also has personally visited localities at Narragansett Pier; near Norfolk, Va. ; on Lake Champlaln, near Plattsburg, and both of us have studied the properties of the sand at Far Rockaway, Long Island. We have therefore (to date), a list of 74 localities In America distributed as follows:

Maine, 3.	Virginia, 6.
Massachusetts, 4.	North Carolina, 16.
New Hampshire, 1.	South Carolina, 1.
Rhode Island, 4.	Michigan, 7.
New York, 12.	Wisconsin, 2
New Jersey, 17.	Nevada, 1.

The number Is constantly Increasing as the reports from keepers of life-saving stations arrive.

To Professor S. F. Balrd we are under obligations for valuable aid in obtaining Information and samples from foreign localities. Through the Smithsonian Institution we have secured specimens of sonorous sand from the Island of Bornholm, Denmark; Colberg, Prussia; and Kauai, Hawaii Islands. Our list of foreign localities now numbers 18, thus making a total of 92. Moreover we have collected through the agencies named and through private hands, over 320 samples of sonorous and non-sonorous sand, the microscopical study of which has occupied one of us for many weeks and the results of which will form a special paper to be presented in connection with this one.

In July and In August of this year, experiments have been conducted both at Manchester-by-the-Sea and at Far Rockaway to determine accurately the properties of the sonorous sand with the object of explaining the cause of its singular characteristics. The results of these experiments are In part as follows.

The loudest sound of which a given sand is capable Is most conveniently produced by confining a quart or more in a bag and strongly striking together the contents. Sounds thus produced were heard distinctly at both the Manchester and Rockaway beaches at a distance of 150 to 200 feet, the distance varying according to the strength and direction of the wind and the interference of the surf noise. At Rockaway a careful experiment was made In fields removed from the beach. The sound produced by striking the bag was heard at a distance of 450 feet measured carefully by a tape line. The sound has a hoot-like quality easily recognized. The experiment was made by four persons, in two pairs, each of which had bags of sand; moreover the experiment was made just at dark so the operators could not be seen by the hearers. A light breeze favored those who heard the sound at 450 feet; the sound was however heard 400 feet against the wind.

The character of the sounds obtained by friction on the beach is decidedly musical and we have been able to indicate the exact notes on a musical staff. The shrillness and lowness of note depend chiefly on the quantity of sand disturbed; by plunging both hands Into the sand and bringing them together quickly with

a swoop a large quantity of the sand vibrates and we hear a tone of which the dominant note is



By stroking the sand nearer the surface and with less force very high notes are heard somewhat confused. The following were heard at different times.



By rubbing firmly and briskly a double handful of the sand several notes on a rising scale are heard, the notes rising as the quantity of sand between the hands diminishes. We do not hear each note of the scale separately, but the ear receives an impression something like that formed by sliding a finger up a violin string at the same time that the bow is drawn.



The range is very remarkable and decided.

These results were obtained at Manchester; the Rockaway beach gave somewhat different tones; the B below the ledger line was not heard at all, but the following notes were heard at different times according to the manner of the friction.

In both cases the notes were determined by comparison with those made on a violin at concert pitch.

The evanescent character of the acoustic quality of the sand is very marked. Sand which has been recently wet requires thorough drying and insolation (?) before it again resumes its acoustic power. Consequently sandy beaches do not always possess the sonorous power in equal measure, and the seeker sometimes falls to discover musical sand in the locality reported. Meteorological conditions, the dryness or moisture of the atmosphere decidedly affect the sonorousness.

Musical sand is easily deprived of its acoustic properties in several ways. Wetting It is effectual of course, but long continued friction between the dry hands also accomplishes the result. The quickest way of "killing" the sand (except by water) is to shake a small quantity in a glass bottle, or better in a tin box. When first agitated in a tin box a peculiar sound is heard which entirely ceases after 20 to 25 slow up and down movements of the box.

Under what circumstances and for how long a period of time sonorous sand will preserve Its quality is a question which at this writing we cannot definitely answer. The results obtained are very conflicting, but we believe that the sand preserves its powers best when hermetically sealed in bottles. When collected In bags It sometimes loses the power In a few hours.

Attempts to restore to "killed" sand (that Is sand rendered mute by any of the above named methods) Its sonorous properties have met with indifferent success; experiments are in progress to accomplish this object.

Experiments made on the beach at Far Rockaway with a gold leaf electro-scope gave no evidence that electricity is concerned in the acoustic phenomenon. The instrument was proved to be sensitive but behaved alike with both sonorous and mute sand. For the use of this Instrument we are under obligations to Dr. Arthur H. Elliott, who also aided in the experiments.

Sonorous and mute sand occur on the beach closely adjoining but they cannot be distinguished by the eye; friction alone determines the difference. In sand of strongly marked acoustic properties a tingling sensation is perceived in the fingers and also in the toes even through boots.

Careful search in literature shows that allusions to sonorous sand are scattered sparingly through writings of a thousand years. An obscure allusion to the phenomenon occurs in one of the singular tales forming the collection known as the Arabian Nights Entertainments. Old Chinese chronicles mention sonorous sand occurring in the desert of Lob-Nor, Marco Polo narrates superstitions concerning it, the Emperor Baber refers to a locality In Afghanistan, and many travellers In the East describe hills of moving sand whence Issue mysterious noises. The famous Jebel Nakous briefly named In our previous paper situated on the east of the Gulf of Suez has been visited by at least six European and American travellers. By comparing their several descriptions we have discovered that they describe not one locality, but two, or possibly three, in the same region. Photographs of two of these localities are herewith exhibited, the first being taken from a view by Lieut. Wellstedt, R. N. and the second from a rough sketch by Prof. H. A. Ward of Rochester. Details of the phenomena reported cannot be given in this abstract; it suffices to say that the dry sand rests on a steep Incline and when agitated slides down the slope with a gradually Increasing noise variously described, but the loudest tones of which are universally compared to distant thunder.

We have also particulars of two localities in Afghanistan both known as Reg Ruwan or Rig-I-Rawan, and of a locality in the desert of Sahara, Africa, where similar phenomena occur.

In conclusion we submit the following brief chronology of the subject.
Chronology.

16th Century.	
1808.	Emperor Baber mentions sonorous sand.
1810.	Dr. Seetzen hears reports of Jebel Nakous.
1818.	Dr. Seetzen visits Jebel Nakous.
1823.	Mr. Gray visits Jebel Nakous.
1829.	Ehrenberg visits Jebel Nakous.
1830.	Ehrenberg publishes his narrative.
1836.	Lieut. Wellstedt visits Jebel Nakous.
1850. (?)	Sir Alex. Burnes visits Rlg-i-Rawan.
1854.	Hugh Miller discovers Eigg locality.
1855.	Kauai described by G. W. Bates.
1868.	Prof. H. A. Ward visits Jebel Nakous (?).
1870-72	Prof. E. H. Palmer visits Jebel Nakous.
1875.	Capt. Lovett visits Rlg-I-Rawan.
	Dr. James Blake examines sand from Kauai.

1876.
1882.

Dr. Meyn describes Bornhotm.
H.C. Bolton visits Manchester, Mass., and
Elgg, Hebrides, and begins a monograph.

ERS-004 A NEW MOUNTAIN OF THE BELL

Bolton, H. Carrington; Nature, 39:607-608, April 25, 1889.

I have just returned from a journey of four weeks in the desert of Mount Sinai, made with the especial object of studying the Jebel Nagous in connection with the joint researches of Dr. Alexis A. Julien and myself on "musical sand." The "Mountain of the Bell" is situated on the Gulf of Suez, about four and a half hours from Tor by the roundabout camel route. It was first described by Seetzen in 1808, since which time it has been visited by Ehrenberg, Gray, Wellstedt, Ruppell, Ward, Newbold, and the late Prof. Palmer, as well as by large numbers of pilgrims. My observations confirm in the main their accounts of the acoustic phenomena heard, but my measurements differ widely from those of all the travellers save Prof. Palmer.

The name Jebel Nagous is given by the Bedouins to a mountain nearly three miles long and about 1200 feet high, composed of white sandstone bearing quartz, pebbles, and veins. On the western and northern sides are several large banks of blown sand, inclined at high angles. The sand on one of these slopes, at the north-west end of the mountain, has the property of yielding a deep resonance when it slides down the incline either from the force of the wind, or by the action of man. This bank of sand I distinguish from the others by calling it the Bell Slope. It is triangular in shape, and measures 260 feet across the base, 5 to 8 feet across the top, and is 391 feet high. It has the high inclination of 31° quite uniformly. It is bounded by vertical cliffs of sandstone, and is broken towards the base by projecting rocks of the same material. The sand is yellowish in colour, very fine, and possesses at this inclination a curious mobility which causes it to flow when disturbed, like treacle or soft pitch, the depression formed being filled in from above and advancing upward at the same time. The sand has none of the characteristics of sonorous sand found on beaches. When pulled downwards by the hands or pushed by the feet a strong vibration is felt, and a low note is plainly heard resembling the deep bass of an organ-pipe. The loudness and continuity of the note are related to the mass of sand moved, but I think that those who compare it to distant thunder exaggerate. The bordering rocky walls give a marked echo, which may have the effect of magnifying and prolonging the sounds, but which, as I afterwards demonstrated, is not essential. There are no cavities for the sand to fall into, as erroneously reported. The peak of Jebel Nagous rises above the Bell Slope to the height of 955 feet above the sea-level, as determined by a sensitive aneroid.

After studying the locality and phenomenon for several days, I formed the opinion that it could not be unique as hitherto supposed, and accordingly I tested every steep slope of blown sand met with on the caravan route northward to Suez. On April 6 I examined a steep sandbank on a hillock only 45 feet high, and was rewarded by the discovery of a second Nagous. This new Nagous is in the Wadi Werdan, only five minutes off the regular caravan route, and one and a half days, by camels, from Suez. The hillock is called by the Bedouins Ramadan, and forms the eastern end of a range of low hills about one quarter of a mile long; being the only hills in the Wadi, the locality can easily be found by travellers. The hills consist of conglomerate and sandstone, and to the west

of gypsum; they slope up gradually from the north and end in bold cliffs on the south side. Sand blown by the north wind is carried over the cliffs, and rests on the steep face at two inclinations, 31° above, and 21° , or less, below. By applying the usual tests with the hands to the fine-grained sand, I found that wherever it lies at the requisite angle to produce mobility (31°), it yielded the bass note, though not so loud as on the Bell Slope of Jebel Nagous. In one instance, my friend and fellow traveller, Mr. Henry A. Sim, of the Madras Civil Service, who kindly aided me in my investigations, heard the sound while standing 100 feet distant. The Nagous sand occurs at intervals throughout the 500 yards of low cliffs; the main bank at the east end being 150 feet wide and 60 feet high measured on the incline. I stirred up the mobile sand pretty thoroughly on this slope, and the next day it failed to give the sounds, not having recovered its properties. The intervening night was very cold (53°). I feel confident that this phenomenon is not very rare in the desert, though the spontaneous production of sounds by sliding of the sand without man's agency, as at Jebel Nagous, may be. Whether the Rig-i-Rawan, north of Cabul, is caused by similar conditions remains to be determined, but I fear that the peculiar relations existing between England and Russia will prevent my visiting Northern Afghanistan. The Bedouins who accompanied us were greatly astounded at my discovery of a new Nagous, and I fear that their faith in a monastery hidden in the heart of Jebel Nagous has received a severe shock. It is interesting to note that the Nagous or modern gong is in daily use in the Monastery of St. Catherine, Mount Sinai.

I made photographs of Jebel Nagous and vicinity, as well as of the new Nagous, and collected specimens of the rocks, sand, &c. This communication must be regarded as a preliminary notice, full details being reserved for the work on "Musical Sand" in preparation by Dr. Julien and myself.

ERS-005 MUSICAL SAND IN CHINA

Offord, Joseph; Nature, 95:65-66, March 18, 1915

Among the immense mass of ancient Chinese records and manuscripts brought back from the buried cities and caves of ancient Khotan, in Central Asia, and now stored in the British Museum, is one called the Tun-Huang-Lu, a topographical description of part of Khotan itself. This little geography was written in the time of the Tang dynasty, in the seventh century, but probably contains matter from earlier authors.

Among the specially interesting natural phenomena of the country described in the Tun-Huang-Lu is a large sandhill, which at certain times gave forth strange noises, so much so that a temple in its vicinity was entitled the "Thunder Sound Temple."

The geographer, speaking specially of the sandhill, says:—"The hill of sounding sand stretches 80 li east and west and 40 li north and south. It reaches a height of 500 ft. The whole mass is entirely constituted of pure sand. In the height of summer the sand gives out sounds of itself, and if trodden by men or horses, the noise is heard 10 li away. At festivals people clamber up and rush down again in a body, which causes the sand to give a loud rumbling sound like thunder. Yet when you look at it next morning the hill is just as steep as before."

Mr. Lionel Giles, from whose translation of the Tun-Huang-Lu these extracts are made, mentions that this sounding sandhill is referred to in another old Chinese book, the WuTai Shih.

ERS-006 MUSICAL SANDS

ERS-006 MUSICAL SANDS

Anonymous: American Meteorological Journal, 1:509, 1885.

In Churchill county, Nevada, there is a traveling mountain of sand. The winds have gathered together a great heap and keep it constantly moving like an immense glacier. It crawls steadily along over valleys and through canyons, never ceasing, the sands making a low, musical sound as they rub against each other, much as they do around the Sphinx every morning at sunrise, which gave rise to the legend that the stony statue was greeting the morning sun with a song. But the moving mountain of Churchill contains still another peculiarity. While its sides are symmetrically formed and lay in folds like solidified waves there is no cone at the top. Instead of going to a peak there is a hole there, made by counter winds, and whoever is rash enough to scale the ridge and pass into that hole pays for his rashness with his life for the fickle sands yield beneath his feet, and the more he struggles to get back the faster he sinks, until he is smothered. The Indians tell of several of their tribe having been thus swallowed up, and no trace has ever been found of them since.

ERS-007 MUSICAL SANDS IN CHILE

Gray, M. H.; Nature, 81:126-127, July 29, 1909.

The interesting letter of Mr. Cams-Wilson, dealing with the existence of musical sands, suggests to me that some fact in my experience relating to this subject may be worth putting on record, and may, through the courtesy of your columns, possibly lead to the elucidation of an occurrence which has hitherto lacked explanation, at least in my mind.

Some few miles to the west of the town of Copiapo, in Chile, and, so far as my recollection of the locality carries me, about half a mile to the southward of the railway line, there is a tailing off of a ragged hill-range, which runs about north and south. In a ravine—it is too small to be called a valley—the sand which covers the greater part of that portion of Chile has, blown doubtless by the sea-breeze, been carried up the gully to which I refer, and lies there at a slope equal to the flowing angle of dry sand. The place is locally known by the name of "El Punto del Diabolo," as, given conditions of wind and weather, which time did not allow me to study, a low moaning sound, varying in intensity, can be heard for quite a quarter of a mile away. Amongst the superstitious natives the place is avoided. Thinking it worth a visit, I went there with the late Mr. Edwards, who was then the British Consul in that district. On our arrival we found that the sands were quite silent, but on making a glissade down the slope a gradually increasing "rumble" was heard, which increased in volume as the sand slid away before us. As the sound increased we were subjected to an undulatory movement, so decided that it was difficult to keep one's balance, and as we both had heard that this sand had swept over an old silver mine, there was a clear impression on the minds of both that the vibration might break in the roof of the old workings. I write of this experience for what it is worth. I do not know whether the ground under the sand was hollow or solid, and although I have ventured to theorise on the subject, as yet I have found no satisfactory solution of this, to me, quite unique experience.

Some rocks and geological features move; some appear and disappear; others have most peculiar properties. The X in the ERX infers that almost anything may be expected in this subsection.

ERX 001 ERUPTING ROCKS

Anonymous; Pursuit, 6:33-35, April 1973.

One of our subscribers, who formerly had a farm near Langley, B. C. Canada, sent us a letter from which we quote the pertinent portions.

"I guess, at some time or other, we've all had to 'pick rocks', and we've had our share of rock-picking. My husband used to (and still does) say they seem to grow out of the ground overnight and I used to agree with him until I noticed something about our North Field. We did very little rockpicking here, mainly just enough to keep large rocks out of the way of the mower, and the only time there seemed a great many was when we'd plowed part of the field. We were there twelve years and gradually I began to notice that it was possible at certain times of the year to walk on that field and find practically no large rocks (over 1-1/2 to 2" in diameter) at all. Now, not finding them didn't (and doesn't) worry me; it's what I found when they were there that's the puzzle. I can't remember why, but one day I turned over one of these rocks and found green grass underneath with only a slight dent in it. I was so surprised that I began turning rocks over all around me. There was only one that was held by the earth and even that had whitish grass roots underneath it, no bare earth; the rest ranged from fresh green grass slightly dented (like the first) to grass turning rusty brown and dying, just as if they [the rocks] were not coming up from below, but going down into the earth."

Mrs. M. notes that her husband "muttered something about the cows kicking them out of the earth, even though some years the cows hadn't been in that field!" Unfortunately we cannot adequately reproduce the color photographs sent as evidence of this peculiar phenomenon; nor can we suggest any definite explanation. Rocks are supposed to work their way gradually toward the surface (this has happened at SITU headquarters)—which brings us to something else

On the 28th February 1973 the Associated Press announced that 30-ton rocks had "erupted" from a previously smooth field on a farm south of Elk City, Oklahoma, and did so, along with a lot of small rocks, apparently "overnight". Allegedly the farmer had pastured his cattle on this field, which lies along a small creek, on the 16th of February. It is not clear exactly when he returned to find that he had a patch of boulders, but it was apparently either the 24th or 25th of February.

We received a large number of clippings on this, including one from the Daily Oklahoman of the 1st March which stated that the experts could not agree on the cause and that "theories abound". In the meantime we had contacted Dr. Robert O. Fay of the Oklahoma Geological Survey, who had first been placed in charge of the investigation by State officials, and he sent us a copy of the official release as well as answering our immediate questions.

The farm is owned by James Walter who has stated that he first noticed rocks emerging from the earth last fall (probably November 1972) but paid little attention to them since he thought that the Shell Oil Company, which has wells in the area, might be excavating for pipeline construction. The major "eruption", however, must have been fairly sudden and was due to a "gas blow-out" (not an explosion) to move some of the chunks of rock. The exact mechanism is, at the time of writing, still under investigation.

Quoting in part from the press release from the Oklahoma Geological Survey, "the center of the site is a shallow cavity paralleling the creek bed, 30 to 50 feet across and about 15 feet deep. The rocks around the cavity are composed of red siltstone and shale from the Doxey Shale, which crops out at the surface, and have been raised and tilted from their normal horizontal position to angles ranging from 28° to 78°. The largest blocks are 3 feet thick, up to 20 feet high, and weigh an estimated 30 tons. Trees along the creek have been uprooted and tilted, and smaller chunks and blocks of siltstone have been thrown as far as 75 feet from the cavity. In addition, several fissures are evident, generally paralleling the creek. No faulting, however, was visible at the surface of the vicinity of the blowout. "

Some of the fissures were more than a foot in width and as much as 10 to 11 feet deep, and in some cases they are apparently still growing; also, there are indications that the rocks are still emerging. The total area affected measures about 230 feet long and 100 feet wide.

Initial investigations by Dr. Fay and others eliminated the possibility that all this was caused by "meteorite impact, volcanic emergence, an earthquake along an existing fault, and an explosion caused by natural gas leaking from a pipeline or from high-pressure reservoirs at depth". Dr. Charles J. Mankin, director of the O. B. S., stated that:

"... it appears likely that the rupture was a nonexplosive blowout caused by the buildup of low-pressure propane gas beneath a relatively weak spot at the surface. The source of the gas was probably a well some 2,000 feet north of the site at Shell Oil Company's natural gas processing plant, where liquefied petroleum gas (LPG), mostly propane, is being pumped into a small underground storage reservoir which has been dissolved from a salt bed in the Blaine Formation about 1,400 feet beneath the surface. "

The Shell Oil Company cooperated fully and their specialists reported to Dr. Fay that they had detected gas in the area (date uncertain—circa 2-3 March) "from analyses which indicated concentrations well above 2 percent—approaching combustible proportions. The gas itself was composed of 85 percent propane. " Inasmuch as all nearby pipelines transport methane, this eliminates a pipeline break as the cause. However, a storage cavity in Shell No. 1-LPG Yelton well was completed in January 1954 and was originally designed to hold 16,000 barrels of liquid propane. Since that date its capacity has increased to 17,500 barrels, "presumably because of the further dissolution of salt by the column of water beneath the propane. . . Shell has reported from its records no loss or significant variation in pressure in the propane storage zone over the past months. "

Dr. Mankin said "This leads to the likelihood that the well bore itself is leaking small but constant amounts of propane to surrounding permeable rocks, possibly because of an inadequate cement bond adjacent to the well casing or of a break in the casing itself. " Dr. Fay told us that the 'leakage' could amount to anything from 1/10th of a barrel per day to 150 barrels if the propane remained liquid. In a liquid state the propane would 'migrate' horizontally through the siltstone and sandstone beds, though moving upward along any fractures or joints in the rocks, and, when sufficiently 'depressurized', turn to a gas and blow out at the surface—in other words, finally give a monumental "push" rather than exploding.

The site has been closed to visitors because of the continued presence of gas—and an accumulation of cigarette butts that indicate that sightseers are unaware of the still present danger of an explosion; and various State and company specialists are attempting to pinpoint the exact position of the leak and to repair it.

Thus what appeared at first glance to be a rather spectacular unexplained

proves to have a mundane explanation, though the phenomenon is rare, to say the least; while the very unspectacular appearance of rocks elsewhere is for the moment unexplained.

And if you are wondering, as we did, why Mr. Walter did not hear anything, his "farm" is a large one—his house is 6 miles from the pasture.

ERX-002 ERUPTING BOULDERS

Fuller, Curtis; Fate, 26:22+, November 1973.

Around the middle of February there was a pasture a short distance south of the Oklahoma town of Elk City. The field was smooth and had a little creek flowing through it. The landowner (unidentified) had pastured his cattle there and watered them in the creek as recently as February 16.

When he returned a few days later he found a crazy jumble of destruction that looked as if a gigantic explosion had taken place underground. Boulders weighing more than 30 tons had erupted. Rocks weighing over 100 pounds had been blown 175 feet away. Trees were tilted at crazy angles, foot-wide cracks had opened in the ground and the creek had disappeared into a kind of cut and now emerged at the other end as a spring.

Dr. Robert Fay of the Oklahoma Geological Survey puzzled over the problem. "You can tell that the rocks just blew out of the ground," he said. "There are indications that they are still emerging."

One reporter said the scene looked "as if a giant bubble had burst from a pudding except that the pudding is of stone and sharp chunks of rock were thrown hundreds of feet."

As this is written no one has explained what transformed a smooth and grassy pasture into a jumble of rocks and boulders some of which tower 20 feet into the air.

ERX-003 THOSE MOVING ROCKS

Fuller, Curtis; Fate, 24:8+, May 1971.

Thirty-eight miles southwest of Scotty's Castle in Death Valley is an uninhabited seven-mile-long, three-mile-wide desert valley which once was a lake bed. Here in one of the hottest driest spots on earth, hundreds of rocks, ranging in size from pebbles to half-ton boulders, move across the surface without apparent means of propulsion, leaving trails that remain visible for many years.

Some time ago Fate ran an article on this mystery. No one implies there is anything supernatural about this but the affair illustrates how complicated even simple matters occasionally get.

Over the years all kinds of solutions have been proposed to explain the moving boulders. Someone even has suggested visitors from outer space move the rocks to confuse us poor mortals. A more mundane proposal is that earthquakes somehow jiggle the rocks about.

Now at last someone is investigating. Dr. Robert P. Sharp, a geologist at Caltech, began his study in 1968. He surveyed the entire dry lake and staked out numerous rocks so he could detect and measure their movements.

ERX 004 MOVING ROCKS

"I was amazed to discover no one ever has carried out a continuous reliable observation program to determine what causes the movement, how often the movement occurs and at what rate," Sharp told Charles Hillinger of the Los Angeles Times.

Sharp staked out his rocks in winter. He not only marked their locations, he marked the rocks and gave them girls' names. And he returns each spring and fall to check the movement of the marked rocks. So far he found that the major movement of the rocks occurred in the month of March 1969.

Sharp reports that a rock named Mary Ann traveled the greatest distance, with a slide of 212 feet in two separate movements. She doubled back and made a loop, he explains. Previously Mary Ann has left trails several hundred feet long. Some of the rock trails, still visible on the dry lake floor, are more than 1500 feet long.

Some geologists believe that ice sheets form over the valley's surface in winter and the rocks move across the ice when the wind blows.

Dr. Sharp doesn't hold with this view. He says the lake bed is filled with dry mud at least 1000 feet deep. When the rare rains come to Death Valley, a small amount will wet the surface and make it slick and greasy. Any additional rainfall would bog the rocks down in the mud—but just wet the surface with 1/4 to 3/8 inches of water and you've set the stage for the rock movement. High winds, he says, must complete the movement.

It is the rocks with flat bottoms that travel over the surface of the lake.

"Mary Ann has a nice flat bottom," Dr. Sharp says.

However, no man ever has seen the rocks actually in motion.

ERX-004 A STREAM OF ALLUVIUM

Conway, Martin; Nature, 59:390, February 23, 1899.

In a private letter, Captain Roberts, Medical Officer at GUGt, sends me the following Information, which may interest some of your readers. He says that near Owir, which is near Drasan in the Turikho valley of Chltral, there is a curious object which he describes as a "glacier of alluvium." It fills the bed of a nullah which comes down from a ridge of Tirich Mir, and is free of snow. It appears to consist entirely of a moving mass of earth, &c. The top of the nullah is at about 12,000 feet and the foot of it at about 5000 feet above sea-level, and it is about five miles long. There is neither ice nor snow above or within this moving mass. It has an undulating, broken surface, and looks like a moraine-covered glacier, except that grass grows upon it in places, and even a few cultivation-terraces have been made upon it by the neighbouring villagers. Its breadth is about 200 yards. There is a stream in a depression on each flank of it, between it and the hillside. The villagers state that it is no new phenomenon. They say that it is always on the move. There are some trees upon it, and by the change in their position, as reported by the natives, it is concluded that the rate of movement is about 200 yards a year. The thing, therefore, is not any sort of mud avalanche. As above stated, parts of the surface are cultivated; but the natives have given up attempting to build houses upon it, because they always tumble down. Captain Roberts is attempting to get a photograph taken of this curious locality.

SECTION ES: STRATIGRAPHIC EVIDENCE

Several geological dogmas are challenged in this section; (1) that coal and oil were formed via the burial and subsequent chemical alteration of organic remains; (2) that the drift and periglacial formations are the work of the Ice Ages; and (3) that the fossil contents of strata are reliable indicators of age. Articles reprinted here demonstrate that one cannot lightly controvert these key foundation stones of geology.

- ESC Coal and petroleum. Stratigraphic data that question the usual theories of formation.
- ESD The drift. Sand, rocks, gravel, and geological debris supposedly deposited during the Ice Ages but which possess many anomalous features. See also ESP.
- ESI "Inverted" strata. Situations where older strata overlie younger strata, contrary to the superposition theorem. The strata involved are usually dated by fossil content, permitting attacks on the validity of evolution.
- ESP Patterned ground. Includes boulder trains and belts, periglacial phenomena. See also ESD.

STRATIGRAPHIC EVIDENCE

The extensive coal measures found around the world exhibit many peculiar features, some of which lead to questions concerning its origin—long believed settled by most geologists—and the validity of the uniformitarian hypothesis in geology.

ESC-001 [THE UNSOLVED ORIGIN OF COAL]

Velikovsky, Immanuel; Earth in Upheaval, Dell Publishing Co., New York, 1965.

In his pursuit of data substantiating terrestrial catastrophism, Velikovsky proposes that the areal extent, thickness, and alternation character of coal beds are not compatible with uniformitarianism.

The origin of the coal beds is still far from being satisfactorily explained. One theory would make peat bogs the place where in a slow process measured by tens and hundreds of thousands of years, coal was born. It is said that the plants fail, but before they decompose in the air they are covered by the water of the swamps. A layer of sand is deposited over them, forming the soil for new plants, and thus the process repeats itself. In order that the layer of sand may be deposited, it is necessary that these marshy regions be covered by water in motion. Since almost regularly marine shells and fossils are found on top of coal beds, the sea must have covered the swamps at one time; then, for new land plants to grow there, the sea must have retreated. There are places where sixty, eighty, and a hundred and more successive beds of coal have formed; this theory would then require that as many times the sea trespassed—when the land slowly subsided—and as many times retreated. In other words, this theory assumes that the ground is pulsating and that the sea will return again sometime and cover the coal beds as it did a hundred times in the past.

"Fossils of marine clams, snails . . . are abundant in the shales just above each seam of coal. Later, with fluctuating sea level, the salt waters withdrew and another freshwater marsh came into being, giving rise to another bed of coal above the earlier one. Again we are surprised, this time by the large number of such alternations of coal with marine sediments; these are now recognized as distinct cycles, each cycle representing a common sequence of events. . . . Ohio displays more than forty such cycles, and in Wales more than a hundred separate seams of coal have been discovered. Marvin Miller has given 400, 000 years as the probable time represented by the average Ohio cycle."

This scheme demands not only that the sea should have covered the land one hundred times but also that after each retreat of the sea a fresh-water marsh should have appeared on the vacant ground in order to give the trees a place to grow and fall down and decay; and that the process of decay should have been checked before going too far, for otherwise the vegetable matter would have disappeared completely and none would have been left in the form of coal." And then each time "not only was the areal extent of the marshes remarkable but the thickness of the coal required a surprising accumulation of vegetable matter." (pp. 216-217)

Velikovsky's alternative is the repetitive accumulation of plant material by terrestrial catastrophes (such as immense floods).

ESC-002 SOME ASPECTS OF THE PALEOECOLOGY OF NON-MARINE FAUNAS _____

Broadhurst, F. M.: American Journal of Science, 262:858-869, 1964.

Fossilized Trees and Rates of Sedimentation. In 1959 Broadhurst and Magraw described a fossilized tree, in position of growth, from the Coal Measures at Blackrod near Wigan in Lancashire. This tree was preserved as a cast, and the evidence available suggested that the cast was at least 38 feet in height. The original tree must have been surrounded and buried by sediment which was compacted before the bulk of the tree decomposed, so that the cavity vacated by the trunk could be occupied by new sediment which formed the cast. This implies a rapid rate of sedimentation around the original tree.

Since this particular tree at Blackrod was described more than fifty trees fossilized in position of growth have been observed in Lancashire, mostly on iron-cast coal workings. These trees are found at various horizons between coal seams, and they occur, also, in partings within coal seams. Where trees occur in the roof beds of a coal seam the root system is developed in the beds above the top of the coal; in no case has a tree been observed to pass from the roof into the coal itself (Gresley, 1887). In most of the trees examined the only part of the original tree to be preserved as a fossil is the outermost region of the trunk which is preserved as a thin layer of coal. Occasionally, however, the original inner cylinder of woody tissue has also been preserved. Identification of many of the trees is difficult, partly on account of the rarity of woody structures preserved fossil and partly because in the Carboniferous *Lycopsidea* the characteristic forms of the leaf bases were lost on the lower part of the trunk due to the production of large amounts of periderm (Eggert, 1961).

Reference to the literature shows that many fossilized trees in position of growth have been found in Lancashire (Jones, Tonks, and Wright, 1938; Tonks and others, 1931, give numerous references to fossil trees; see also Aitken, 1880; Wild, 1884). It is clear that trees in position of growth are far from being rare in Lancashire (Teichmüller, 1956, reaches the same conclusion for similar trees in the Rhein-Westfalen Coal Measures), and presumably in all cases there must have been a rapid rate of sedimentation. This sedimentation occurred, without doubt, in water that could not have been fast-flowing since the trees were left in standing position. It is possible that the land surface with its trees was inundated by flood water (possibly on numerous successive occasions) from adjacent waterways, the flood water bringing with it large amounts of sediment. This mechanism has been advocated to explain the occurrence of trees in position of growth in the Coal Measures of Germany (Teichmüller, 1956) and in the Trias of Colorado (Holt, 1947). The significance of the upright trees in Lancashire, so far as this study is concerned, is that they were all found enclosed by fine sandstones, siltstones, and coarse-grained mudstones but not by the fine-grained sediments, including those containing shells. The most likely explanation of the apparent absence of such trees from these sediments is that the latter accumulated too slowly: any trees decayed and collapsed before they could be enclosed by sediment, (pp. 865-866)

The implication is one of very rapid sedimentation—that is, catastrophism

A century ago, the layers, terraces, mounds, and other accumulations of sand, gravel, and boulders that are strewn across northern climes were collectively called "drift". Although challenged by some, such as Ignatius Donnelly, the glacial theory has seemed to be the best explanation of the drift. Nevertheless, doubts persist, and these doubts are founded on "problems" encountered in trying to explain peculiar features of the drift using glacial theory. Subsection ESD comes to grips with the drift and the supposed shortcomings of the Ice Age approach. Section ESP also contains descriptions of unusual geological features that have been declared glacial or periglacial in origin.

ESD-001 A COMET CAUSED THE DRIFT

Donnelly, Ignatius; Ragnarok: The Age of Fire and Gravel, University Books, New York, 1970. (Originally published 1883)

Ignatius Donnelly, after much library research of a type similar to that used in preparing these sourcebooks, evolved the thesis that a comet brought on the supposed Ice Ages. His Chapter I of Ragnarok is a succinct statement of his hypothesis and is well worth reproducing for itself and as an example of Donnelly's style.

Now, good reader, we have reasoned together up to this point. To be sure, I have done most of the talking, while you have indulged in what the Rev. Sydney Smith called, speaking of Lord Macaulay, "brilliant flashes of silence."

But I trust we agree thus far that neither water nor ice caused the Drift. Water and ice were doubtless associated with it, but neither produced it.

What, now, are the elements of the problem to be solved?

First, we are to find something that instantaneously increased to a vast extent the heat of our planet, vaporized the seas, and furnished material for deluges of rain, and great storms of snow, and accumulations of ice north and south of the equator and in the high mountains.

Secondly, we are to find something that, coming from above, smashed, pounded, and crushed "as with a maul," and rooted up as with a plow, the gigantic rocks of the surface, and scattered them for hundreds of miles from their original location.

Thirdly, we are to find something which brought to the planet vast, incalculable masses of clay and gravel, which did not contain any of the earth's fossils; which, like the witches of Macbeth,

"Look not like th' inhabitants of earth,
And yet are on it;"

which are marked after a fashion which can not be found anywhere else on earth; produced in a laboratory which has not yet been discovered on the planet.

Fourthly, we are to find something that would produce cyclonic convulsions upon a scale for which the ordinary operations of nature furnish us no parallel.

Fifthly, we are to find some external force so mighty that it would crack the crust of the globe like an eggshell, lining its surface with great rents and seams, through which the molten interior boiled up to the light.

Would a comet meet all these prerequisites?

I think it would.

Let us proceed in regular order. (PP- 63-64)

ESD 002 [STRANGE ASPECTS OF THE DRIFT]

Donnelly, Ignatius; Ragnarok: The Age of Fire and Gravel, University Books, New York, 1970. (Originally published 1883)

In his analysis of the character of the drift, Donnelly suggests some "perplexities."

And here is another perplexity: It might naturally be supposed that the smoothed, scratched, and smashed appearance of the underlying rocks was due to the rubbing and rolling of the stones under the ice of the glaciers; but, strange to say, we find that—

"The scratched and polished rock-surfaces are by no means confined to **Un**-covered districts. They are met with everywhere and at all levels throughout the country, from the sea-coast up to near the tops of some of our higher mountains. The lower hill-ranges, such as the Sidlaws, the Ochils, the Pentlands, the Kilbarchan and Paisley Hills, and others, exhibit polished and smoothed rock-surfaces on their very crest. Similar markings streak and score the rocks up to a great height in the deep valleys of the Highlands." (Geike: The Great Ice Age)

We can realize, in our imagination, the glacier of the mountain-valley crushing and marking the bed in which it moves, or even the plain on which it discharges itself; but it is impossible to conceive of a glacier upon the bare top of a mountain, without walls to restrain it or direct its flow, or higher ice accumulations to feed it.

Again:

"If glaciers descended, as they did, on both sides of the great Alpine ranges, then we would expect to find the same results on the plains of Northern Italy that present themselves on the low grounds of Switzerland. But this is not the case. On the plains of Italy there are no traces of the stony clay found in Switzerland and all over Europe. Neither are any of the stones of the drift of Italy scratched or striated." (Ibid)

But, strange to say, while, as Geike admits, no true "till" or Drift is now being formed by or under the glaciers of Switzerland, nevertheless "till" is found in that country dissociated from the glaciers. Geike says:

"In the low grounds of Switzerland we get a dark, tough clay, packed with scratched and well-rubbed stones, and containing here and there some admixture of sand and irregular beds and patches of earthy gravel. This clay is quite unstratified, and the strata upon which it rests frequently exhibit much confusion, being turned up on end and bent over, exactly as in this country the rocks are sometimes broken and disturbed below till. The whole deposit has experienced much denudation, but even yet it covers considerable areas, and attains a thickness varying from a few feet up to not less than thirty feet in thickness." (Ibid)

Here, then, are the objections to this theory of the glacier-origin of the Drift:

- I. The glaciers do not produce striated stones.
- II. The glaciers do not produce drift-clay.
- III. The glaciers could not have formed continental sheets of "till."
- IV. The glaciers could not have existed upon, and consequently could not have striated, the mountain-tops.
- V. The glaciers could not have reached to the great plains of the continents far remote from valleys, where we still find the Drift and drift-markings.
- VI. The glaciers are limited in number and confined in their operations, and were utterly inadequate to have produced the thousands of square miles of drift-debris which we find enfolding the world.

But let us look at another point:

If the vast deposits of sand, gravel, clay, and boulders, which are found in Europe and America, were placed there by a great continental ice-sheet, reaching down from the north pole to latitude 35° or 40° ; if it was the ice that tore and scraped up the face of the rocks and rolled the stones and striated them, and left them in great sheets and heaps all over the land—then it follows, as a matter of course, that in all the regions equally near the pole, and equally cold in climate, the ice must have formed a similar sheet, and in like manner have torn up the rocks and ground them into gravel and clay. This conclusion is irresistible. If the cold of the north caused the ice, and the ice caused the Drift, then in all the cold north-lands there must have been ice, and consequently there ought to have been Drift. If we can find, therefore, any extensive cold region of the earth where the Drift is not, then we can not escape the conclusion that the cold and the ice did not make the Drift.

Let us see: One of the coldest regions of the earth is Siberia. It is a vast tract reaching to the Arctic Circle; it is the north part of the Continent of Asia: it is intersected by great mountain-ranges. Here, if anywhere, we should find the Drift; here, if anywhere, was the ice-field, "the sea of ice." It is more elevated and more mountainous than the interior of North America where the drift-deposits are extensive; it is nearer the pole than New York and Illinois, covered as these are with hundreds of feet of debris, and yet there is no Drift in Siberia!

I quote from a high authority, and a firm believer in the theory that glaciers or ice-sheets caused the drift; James Geikie says:

"It is remarkable that nowhere in the great plains of Siberia do any traces of glacial action appear to have been observed. If cones and mounds of gravel and great erratics like those that sprinkle so wide an area in Northern America and Northern Europe had occurred, they would hardly have failed to arrest the attention of explorers. Middendorff does, indeed, mention the occurrence of trains of large erratics which he observed along the banks of some of the rivers, but these, he has no doubt, were carried down by river-ice. The general character of the 'tundras' is that of wide, flat plains, covered for the most part with a grassy and mossy vegetation, but here and there bare and sandy. Frequently nothing intervenes to break the monotony of the landscape. . . . It would appear, then, that in Northern Asia representatives of the glacial deposits which are met with in similar latitudes in Europe and America do not occur. The northern drift of Russia and Germany; the asar of Sweden; the kames, eskers, and erratics of Britain; and the iceberg-drift of Northern America have, apparently, no equivalent in Siberia. Consequently we find the great river-deposits, with their mammalian remains, which tell of a milder climate than now obtains in those high latitudes, still lying undisturbed at the surface." (Ibid)

Think of the significance of all this. There is no Drift in Siberia; no "till" no "boulder-clay," no stratified masses of gravel, sand, and stones. There was, then, no Drift age in all Northern Asia, up to the Arctic Circle! (PP- 121-122)

ESD-003 SOME DEFECTS OF GLACIAL THEORY

Davis, Chester A. ; New World Antiquity. 19-27-43. March/April 1972.

No sourcebook of controversial geology would be complete without some critiques of the glacial theory (usually by amateurs these days). New World Antiquity is

published by Markham House Press, London, and is edited by Egerton Sykes, an Atlantist and follower of Hoerbiger. This article poses the very same questions that were debated when the Glacial Theory was first promulgated. These questions remain unanswered in the minds of some.

There are a small number of presently accepted views of the ice and drift which, upon serious analysis, are found to be questionable.

The first belief to be questioned is that glaciers can transport boulders upgrade for long distances.

The envisioned Keewatin glacier has been reported to have moved erratics in Canada to an altitude 3,000 feet higher than their source.

Glaciers move at a snail's pace down mountain valleys. They move somewhat reluctantly from two to four meters per day. To move, they must overcome the resistance provided by the irregularities of the valleys. They do work in overcoming the opposition of resistant masses of rock protruding in places from the mountains. They do work in scratching, scouring and polishing the valley floors and the mountain sides. It is largely by a continual re-arrangement of ice molecules that glaciers are gravitationally moved downhill to become thicker at the tongue.

After a moment's reflection, it is seen that this increased depth of ice at the glacier's tongue indicates that the terrain is offering a resistance to the glacier's advance. Yet the ice of the Keewatin glacier has been considered as being exactly the opposite: thick at the source—where no mountains exist—and being of such height and slope that it has been credited with pushing boulders uphill for 500 miles.

Second, the formation of crossing boulder trains by glaciers in the New England States is a questionable matter.

This objection is raised because distinct boulder-distribution patterns from point sources are known to cross each other, and to exist inside the larger pattern of another, as shown in Figure 1. (Figures not reproduced)

Serious reflection suggests that it would have been mechanically impossible for a glacier, or glaciers, to make the crossing boulder trains, whether this was done by contemporaneous glaciers or not.

Richard Foster Flint was concerned with this perplexing matter, for he recognized that they could not have been produced contemporaneously. But we can see that the insertion of a period of time to separate the glacial action, or even with changes in the thickness of the glacier, these could still not solve the basic mechanical problem.

We realize that if a glacier has any eroding and motivating power at all—and it evidently would have if it was producing a boulder train—the action taking place in making a second boulder train in the same area would obliterate a previously positioned boulder train.

A third objection to accepted glacial theory is directed against the view that the glaciers invaded the Great Lakes Region and that the Great Lakes basins were enlarged by glacial scour, and scooped-out by glacial movement.

While it is logical to conclude that glaciers can move material, it becomes questionable—in the light of a recent discovery—that the Keewatin and Labradorian glaciers enlarged or scooped-out the Great Lakes basins.

The discovery that negates the glacial scouring and scooping so well is the finding of several craters in Canada by several distinguished Canadian astronomers and geologists. These craters have been found to contain some very old material, and they are referred to as "fossil" craters.

There are quite a number of them. However, we can only consider two. The Brent Crater, which is 3.2 km in diameter, (2 miles) and the Holleford Crater, which is 2.33 km in diameter, (1.46 miles) are located just north of

Lake Ontario, as shown in Figure 2.

It may be immediately seen from Figure 2 that such powerful eroding action as would have been necessary to scour or even scoop-out (excavate) Lake Ontario's basin even a small amount would probably have destroyed these significant craters. But from the location of these craters, and the fact that they have not been obliterated, the movement of glaciers across them is negated.

A fourth probable defect in present glacial theory is the generally accepted belief that glaciers produced an extremely attenuated border and moved as far south as shown in Figure 3.

It is logical for us to believe that a glacier terminating on land would make and leave a distinct terminal moraine. But such moraine was not found in eastern and central North America, as shown by the following: In 1881, G. Frederick Wright, and others, had hopes of tracing a distinct line of terminal moraines across the continent, but were compelled to abandon this view because they found the marginal deposits to be more evenly spread, ending in some cases in an extremely attenuated border.

Since distinct terminal moraines were not found by Wright and others, we may deduce that something is seriously wrong; that the distribution of the material need not necessarily have been by glacial action. We will soon see how the various "drift" formations were quite possibly made.

The fifth questionable matter of Ice Age theory concerns the belief that glaciers produced the approximately 18,000 cigar-shaped drumlins which exist east of Rochester, N. Y.

It is admitted that the north-south alignment of these drumlins does fit the glacial concept of their making perfectly. But the mechanism of drumlin formation must be questioned, from the observation that one-half of a cigar-shaped lake basin now exists near Savannah, New York.

A moments reflection suggests that whatever the mechanism of drumlin formation may be, it would certainly appear to be incompatible with the means of simultaneously excavating a cigar-shaped lake basin. Further, as from objection number three, since glacial action did not destroy the Brent and Holleford Craters, it becomes improbable that glaciers could have moved across the Great Lakes basins to make the drumlins and this swell lake basin.

At this point, it would be most natural for one to raise the question: If the Great Lakes basins were not scooped-out or even scoured-out by the advancing rock shod glaciers, then how is it possible for the thousands of drumlins to have been made south of Lake Ontario?

ESD-004 CATASTROPHISM AND EVOLUTION

King, Clarence; American Naturalist, 11:449-470, August 1877.

In 1877, some scientists still held to the doctrine of catastrophism and expressed themselves freely. King, in fact, defends the waning doctrine with great eloquence—and at such great length that only a few paragraphs can be reproduced here.

The earliest geological induction of primeval man is the doctrine of terrestrial catastrophe. This ancient belief has its roots in the actual experience of man, who himself has been witness of certain terrible and destructive exhlbl-

tions of sudden, unusual telluric energy. Here In America our own species has « seen the vast, massive eruptions of Pliocene basalt, the destructive invasion of northern lands by the slow-marching ice of the glacial period, has struggled with the hardly conceivable floods which marked the recession of the frozen age, has felt the solid earth shudder beneath Its feet and the very continent change Its configuration. Yet these phenomena are no longer repeated; nothing comparable with them ever now breaks the geologic calm.

Catastrophism is therefore the survival of a terrible impression burned in upon the very substance of human memory. The doctrine was also arrived at In very early times by our modern method of reasoning from marine fossils observed to be entombed In rocky beds far removed from the present seas,—beds which compel the natural Inference that they are sea bottoms upheaved. This Induction is poetically touched In the Rig Vedas, Is stated in scientific method with surprising frequency among the Greeks, and recurs in the writings of most earth-students ever since.

Plutarch in his *Morals* gives a vivid account of an interview between an Egyptian priest and wise Solon, who, in the open-mindedness of a truly great man searching after immemorial knowledge, had come to sit at his feet to listen. Calmly and with the few broad touches of a master, In that simple eloquence which comes of really knowing, the priest tells him of the catastrophes of submergence and upheaval which the earth's surface has suffered; and his method was identically ours of to-day. What a picture! Solon the wise, Inheritor of the Hellenic culture, master of the polished learning of his country and his day, sitting within the shades of that hoary temple, listening devoutly to the words of one who spoke as out of the dark vault of the past and told how the solid continents were things of a time, born but lately from the womb of the sea.

When complete evidence [In the "auriferous" gravels] of the antiquity of man In California and the catastrophes he has survived come to be generally understood, there will cease to be any wonder that a theory of the destructive In nature Is an early, deeply rooted archaic belief, most powerful in Its effect on the Imagination. Catastrophe, speaking historically, is both an awful memory of mankind and a very early piece of pure scientific Induction. After it came to be woven into the Sanskrit, Hebrew, and Mohammedan cosmogonies, Its perpetuation was a matter of course.

From the believers In catastrophe there Is, however, a totally different class of minds, whose dominant characteristic Is a positive refusal to look further than the present, or to conceive conditions which their senses have never reported. They lack the very mechanism of Imagination. They suffer from a species of Intellectual near-sightedness too lamentably common among all grades and professions of men. They are bounded—I might almost say Imprisoned—by the evident facts and ideas of their own to-day and their own environment. With that sort of detective sharpness of vision which is often characteristic of those who cannot see far beyond their noses, these men have most ably accumulated an Impressive array of geological facts relating to the existing operation of natural laws. They have saturated themselves with the present modus operandi of geological energy, and culminating In Lyell have founded the British School of Uniformitarianism.

Men are born either catastrophists or uniformitarians. You may divide the race into imaginative people who believe in all sorts of Impending crises,—physical, social, political,—and others who anchor their very souls in statu quo. There are men who build arks straight through their natural lives, ready ToFthe first sprinkle, and there are others who do not watch Old Probabilities or even own an umbrella. This fundamental differentiation expresses Itself

in geology by means of the two historic sects of catastrophists and uniformitarians. (pp. 450-452)

Here is the classic definition of Uniformitarianism.

Sweeping catastrophism is an error of the past. Radical uniformitarianism, however, persists, and probably controls the faith of a majority of geologists and biologists. A single extract from so late and so important a book as Croll's *Climate and Time* will serve to show how strong men still believe in what may be called homoeopathic dynamics. Speaking of uniformitarianism, Croll says: "This philosophic school teaches, and that truly, that the great changes undergone by the earth's crust must have been produced, not by convulsions and cataclysms of nature, but by those ordinary agencies that we see at work every day around us, such as rain, snow, frost, ice, and chemical action, etc."

The tenets of catastrophism here stated are as dogmatic as those of uniformitarianism. The geological facts are rarely at issue. The controversy centers on opinions, such as those below.

If poor, puny little Vesuvius could immortalize itself by burying the towns at its feet, if the feeble energy of a Lisbon earthquake could record itself on the grave-stones of thousands of men, then the volcanic period in Western America was truly catastrophic. Modern vulcanism is but the faint, flickering survival of what was once a world-wide and immense exhibition of telluric energy, one whose distortions and dislocations of the crust, whose deluges of molten stone, emissions of mineral dust, heated waters, and noxious gases could not have failed to exert destructive effect on the life of considerable portions of the globe. It cannot be explained away upon any theory of slow, gradual action. The simple field facts are ample proof of the intensity and suddenness of Tertiary vulcanism.

Of climate catastrophes we have the record of at least one. When the theory of a glacial period came to be generally accepted, and the destructive effects of the invasion of even middle latitudes by polar ice were realized, especially when the devastating effects of the floods which were characteristic of the recession of the ice came to be studied, uniformitarianism pure and simple received a fatal blow. I am aware that British students believe themselves justified in taking uniformitarian views of the boulder-till, but they have yet to encounter phenomena of the scale of our Quaternary exhibitions.

A most interesting comparison of the character and rate of stream erosion may be obtained by studying in the western Cordilleras, the river work of three distinct periods. The geologist there finds preserved and wonderfully well exposed, first, Pliocene Tertiary river valleys, with their boulders, gravels, and sands still lying undisturbed in the ancient beds; secondly, the system of profound canons, from 2000 to 5000 feet deep, which score the flanks of the great mountain chains, and form such a fascinating object of study, and not less of wonder, because the gorges were altogether carved out since the beginning of the glacial period; thirdly, the modern rivers, mere echoes of their parent streams of the early Quaternary age. As between these three, the early Quaternary rivers stand out vastly the most powerful and extensive. The present rivers are utterly incapable, with infinite time, to perform the work of glacial torrents. So, too, the Pliocene streams, although of very great volume, were powerless to wear their way down into solid rock thousands of feet, at the rapid rate of the early Quaternary floods. Between these three systems of rivers is all the difference which separates a modern (uniformitarian) stream and a terrible catastrophic engine, the expression of a climate in which struggle for

existence must have been something absolutely inconceivable when considered from the water precipitations, floods, torrents, and erosions of to-day.

Uniformitarians are fond of saying that give our present rivers time, plenty of time, and they can perform the feats of the past. It is mere nonsense in the case of the canons of the Cordilleras. They could never have been carved by the pigmy rivers of this climate to the end of infinite time. And, as if the sections and profiles of the canons were not enough to convince the most skeptical student, there are left hundreds of dry river-beds, within whose broad valleys, flanked by old steep banks and eloquent with proofs of one-powerful streams, there is not water enough to quench the thirst even of a uniformitarian. Those extinct rivers, dead from drought, in connection with the great canon system, present perfectly overwhelming evidence that the general deposition of aerial water, the consequent floods and torrents, forming as they all do the distinct expression of a sharply-defined cycle of climate, as compared either with the water phenomena of the immediately preceding Pliocene age or with our own succeeding condition, constitute an age of water catastrophe whose destructive power we only now begin distantly to suspect.

I have given you what in my belief are sound geological conclusions, the want of time alone causing me to waive the slow production of proofs. I believe I am fully prepared to sustain the assertions, first, that the rate of physical change progressing to-day in all departments of terrestrial action is inadequate to produce the grander features of American geological history; secondly, that in the past, at intervals, the dynamic rate has been so sharply accelerated as to bring about exceptional results; thirdly, that these results have been catastrophic in their effect upon the life of America and the bounding oceans. I have called the revolutions in the American area catastrophic because any disturbances of land or sea, of the described scale, intensity, and rapidity, could not fail to have a disastrous effect on much of the organic world. The uniformitarian school would accept these crust changes with unruffled calmness; they would read the record exactly as a catastrophist might, only they would assume unlimited time and their inch-by-inch process. The analogy of the present, they say, is against any acceleration of rate. In the past, and besides, the geological record is a very imperfect document which does not disprove our view. In plain language, they start with a gratuitous assumption (vast time), fortify it by an analogy of unknown relevancy (the present rate), and serenely appeal to the absence of evidence against them as proof in their favor. The courage of opinion has rarely exceeded this specimen of logic. If such a piece of reasoning were uttered from a pulpit against evolution, biology would at once take to her favorite sport of knuckle-rapping the clergy. In the manner we are all of us accustomed to witness. In forbidding us to look for past rates of change differing from the present, the British uniformitarians have tied the hands of the science. By preaching so eternally from the text of "Imperfection of the geological record," they have put blinders on the profession. A few more such doctrines will reduce the science to a corpse, around which teleologists and biologists might hold any sort of funeral dance their fancy dictated. Now, because the record is not altogether made out is no proof whatever that it never will be. There was once a discovery of a very small piece of evidence, the Rosetta Stone, which served as a key to a vast amount of previously illegible material. Geology, if not strangled in its own house, will, in my belief, go on and dig up enough Rosetta Stones to translate the strata into a precise language of energy and time. (pp. 460-462)

Darwin, who in his day has caught the one syllable from nature's lips, advances always with caution, and although he practically rejects does not

positively deny the existence of sudden great changes in the earth's history. Huxley, permeated in every fibre by belief in evolution, feels that even to-day catastrophism is not yet wholly out of the possibilities. It is only lesser men who bang all the doors, shut out all doubts, and flaunt their little sign, "Omniscience on draught here." It must be said, however, that biology, as a whole denies catastrophism in order to save evolution. It is the common mistake of biologists to assume that catastrophes rest for their proof on breaks in the palaeontological record, meaning by that the observed gaps of life or the absence of connecting links of fossils between older and newer sets of successive strata. There never was a more serious error. Catastrophes are far more surely proved by the observed mechanical rupture, displacement, engulfment, crumpling, and crushing of the rocky surface of the globe. Granted that the evidence would have been slightly less perfect had there been no life till the present period, still the reading would have been amply conclusive. The palaeontological record is as imperfect as Darwin pleads, but the dynamic record is vitiated by no such ambiguity, (pp. 463-464)

From a comparison of the list and character of geological changes in America with those mysterious lines across which no species march, I feel warranted in harboring the belief that catastrophe was an integral part of the cause; changed life, the effect. Biologists are accustomed to explain the cause of a great gap like that which divides the Palaeozoic and Mesozoic life by an admission that the Palaeozoic forms ceased to live, but that the succeeding changed forms at the beginning of the Mesozoic were not the local progeny, greatly modified by catastrophic change, but merely immigrants from some other conveniently assumed country. They succeed in rendering this highly probable, if not certain, in many instances. But they are estopped from always advancing this migration theory. Greek art was fond of decorating the friezes of its sacred edifices with the spirited form of the horse. Times change; around the new temple of evolution the proudest ornament is that strange procession of fossil horse skeletons, among whose captivating splint-bones and general anatomy may be described the profiles of Huxley and Marsh. Those two authorities, whose knowledge we may not dispute, assert that the American genealogy of the horse is the most perfect demonstrative proof of derivative genesis ever presented. Descent they consider proved, but the fossil jaws are utterly silent as to what the cause of the evolution may have been.

I have studied the country from which these bones came, and am able to make this suggestive geological commentary. Between each two successive forms of the horse there was a catastrophe which seriously altered the climate and configuration of the whole region in which these animals lived. Huxley and Marsh assert that the bones prove descent. My own work proves that each new modification succeeded a catastrophe. And the almost universality of such coincidences is to my mind warrant for the anticipation that not very far in the future it may be seen that the evolution of environment has been the major cause of the evolution of life; that a mere Malthusian struggle was not the author and finisher of evolution; but that He who brought to bear that mysterious energy we call life upon primeval matter bestowed at the same time a power of development by change, arranging that the interaction of energy and matter which make up environment should, from time to time, burst in upon the current of life and sweep it onward and upward to ever higher and better manifestations. Moments of great catastrophe, thus translated into the language of life, become moments of creation, when out of plastic organisms something newer and nobler is called into being, (pp. 469-470)

ESD-005 THE NATURE OF THE ENGLACIAL DRIFT OF THE MISSISSIPPI BASIN

Chamberlain, T. C. ; Journal of Geology, 1:47-60, 1893.

The boulder "belts" described by Chamberlain (of "nebular hypothesis" fame) are classified with patterned ground and boulder trains; all of which are ascribed to the action of ice and glaciers, never to floods or catastrophic events.

One of the most remarkable expressions of the drift phenomena of the Upper Mississippi region consists of belts of boulders stretching for great distances over the face of the country, and disposing themselves in great loops after the fashion of the terminal moraines of the region with which they are intimately connected. Besides this, there are numerous patches of boulders of more or less irregular form and uncertain relations. The whole of these have not been studied in detail, but a sufficient portion of them have received careful examination to justify the drawing of certain conclusions from them. Those which have been most studied lie in Ohio, Indiana, Illinois, Michigan, Wisconsin, Iowa and Dakota. Those of the first three States have been most carefully traced and their constitution is such as to give them the greatest discriminative value. To these our discussion will be limited chiefly.

Emerging from the dunes at a point north of the Iroquois river in Jasper county, northwestern Indiana, a well characterized belt of surface boulders stretches westward to the State line, just beyond which it curves about to the south and then to the east, and re-enters Indiana a little south of the northwest corner of Benton county. It soon turns abruptly to the south and reaches the Wabash river near the centre of Warren county. The immediate valley of the Wabash is thickly strewn with boulders from the point where the belt reaches it to the vicinity of West Point on the western line of Tippecanoe county. The uplands, however, do not give any clear indication of the continuity of the belt, and the connection is not altogether certain. There is an inner well-marked belt that branches away from this in the central part of Benton county and runs southeasterly into the northwestern quarter of Tippecanoe county, beyond which only scattered boulders occur, which leaves its precise connections also in doubt. But starting from West Point, which is less than a dozen miles from the point where the two belts cease to be traceable with certainty, a well-defined belt, one or two miles wide, runs southeasterly across the southwestern corner of Tippecanoe county and the northeastern quarter of Montgomery county to the vicinity of Darlington, beyond which its connection is again obscure, although boulders occur frequently between this point and the northwestern corner of Brown county, where boulders are very abundant. So also, patches of exceptionally abundant boulders occur in the west central part of Clinton county. These may be entitled to be regarded as a connecting link between the train which enters northwestern Tippecanoe county and that of northwestern Boone county, as scattered boulders of the surface type, but of not very exceptionally frequent occurrence, lie between them. However this may be, a belt of much more than usually frequent surface boulders stretches southeasterly to the vicinity of Indianapolis, and probably connects with a very well-marked belt lying near the south line of the southeast quarter of Marion county and in the northeastern part of Johnson county. There is also a well-defined tract in southeastern Hendricks county, running east and west, without evident connection with the foregoing tracts, though it may be the equivalent of the Darlington belt. There is also a somewhat unusual aggregation in the form

of irregular belts in southeastern Johnson county, in the vicinity of Nineveh, and in southern Shelby county. The belt south of Indianapolis is probably to be correlated by scattered boulders only slightly more abundant than those of the adjacent region, but of the surface type, stretching northeasterly to near the center of the west half of Henry county, where a well-marked belt again sets in. From this point the tract runs northeasterly nearly to the north limit of the county, where it turns easterly and runs in the vicinity of the line between Randolph and Wayne counties to near the Ohio line, where it curves to the southeast entering Ohio near the northwest corner of Preble county. In its southeasterly course across that county it is phenomenally developed as has been well shown by the descriptions of Professor Orton. Soon after entering Montgomery county it curves about to a northeasterly course, and crossing the great Miami river, a few miles above Dayton, holds its northeast course across the southeastern part of Miami county, the northwestern part of Champaign county, and thence on to about the center of Logan county, where it curves about and runs in a direction a little east of south to near the southeast corner of Champaign county, beyond which it ceases to be a specially notable phenomenon.

In the region between the Wabash and Kankakee rivers, in northern Indiana, there are numerous tracts of irregular form over which surface boulders in phenomenal abundance are scattered. These are particularly noticeable in southern Jasper county; in the vicinity of Wolcott, Monon and Chalmers in White county; near Star City in Pulaski county; in the southeastern corner of Stark county, and very generally along the great interlobate moraines, lying parallel with the Eel river, and some others of the Saginaw glacial lobe. These are so associated with the inter-tangled morainic phenomena of that region as not to admit of convenient and brief description in their genetic relationships.

The well-defined tracts have a most significant distribution. The first part described is associated with the terminal moraine that marked the margin of a lobe of ice that moved westward along the axis of the Iroquois basin to a point a few miles beyond the Indiana-Illinois line. The portion that runs southward to the Wabash is associated with the moraine that follows the same course, and runs at right angles over the older moraines of the Lake Michigan lobe. The tract is Tippecanoe and Montgomery counties, that in south Marion county, and that in Henry and Randolph counties, in the eastern part of the state, are associated with the terminal moraines that form a broad loop with the West White river basin lying in its axis. In western Ohio the belt is intimately associated with a moraine that bordered the Miami lobe of the ice sheet, and the south-trending portion in eastern Logan and Champaign counties lies on the western margin of the Scioto lobe.

The relationship of these tracts to terminal moraines is very clear and specific. They constitute marginal phenomena of the ancient ice sheet. Their distribution completely excludes their reference to floating ice, for they not only undulate over the surface utterly negligent of any horizontal distribution, but they are disposed in loops. In crossing the basins of the region, and the convexities of these loops are turned down stream. These basins for the most part open out in southerly or westerly directions which make it improbable that ice-bearing bodies of water occupied them. But if this were not fatal, certainly the fact that the convexities of the boulder belts are turned down stream and cross the centers of the basins is precisely contrary to the distribution they must have assumed if they were due to floating ice in bodies of water occupying the basins. I hold it, therefore, to be beyond rational question that these tracts were deposited as we find them by the margins of the glacial lobes that invaded the region.

If these boulder belts were of the same nature as the average boulders of the till-sheets beneath them, then the simple fact of unusual aggregation might be plausibly referred to the accidents of gathering and deposition. But they are very clearly distinguished from the average boulders of the till by several characteristics.

1. They are superficial. Sometimes they rest completely on the surface, sometimes they are very slightly imbedded, sometimes half buried, sometimes they protrude but a slight portion, and sometimes they are entirely concealed, but lie immediately at the surface. In all cases the aggregation is distinctly superficial. Where they are buried, the burying material is usually of different texture and composition from the subjacent till, and appears to be distinct in origin from it. The superficiality of the tract is very obvious almost everywhere, and is especially so in regions where the subjacent till is of the pebble-clay rather than boulder-clay order, for the comparative absence of boulders below emphasizes the contrast. Throughout most of the region the subjacent till is not of a very bouldery type, so that the distinction is generally a marked one.

2. The boulders of the belts are almost without exception derivatives from the crystalline terranes of Canada. Those of the great tract especially under consideration were derived from the typical Huronian rocks of the region north of Lake Huron, and from granitic and gneissoid rocks referable to the Laurentian series of the same region. These last, however, cannot be sharply distinguished from the granitic rocks derived from other parts of the Laurentian terrane. The Huronian rocks are very easily identified because of the peculiarities of some of the species. Among these the one most conspicuously characterized is a quartz-and-jasper conglomerate. The matrix is usually a whitish quartzite. This is studded with pebbles of typical red jasper and of duller rocks of jasperoid nature, which grade thence into typical quartzite pebbles. With these are mingled crystalline pebbles of other varieties. Another peculiar erratic comes from the "slate conglomerate" of Logan. It consists of a slaty matrix through which are scattered rather distantly pebbles of granitic, quartzitic and other crystalline rocks. This is one of the forms of the "basal conglomerate" of Irving. Other varieties of this "basal conglomerate" are present. In addition to these very peculiar rocks, a quartzite of a very light greenish semi-translucent hue has a wide distribution along the tract. It is readily distinguishable from the numerous other quartzites of the drift of the interior. Some years since, on returning from my first field examination of a portion of this belt, I sent a typical series of chips from the characteristic erratics to Professor Irving, who had recently returned from the study of the original Huronian region. He returned a suite of chippings that matched them perfectly throughout, all of which were taken in situ in the region north of Lake Huron.

Among the boulders of the belt are occasionally found specimens of impure limestone or of limy sandstone that might perhaps be referred doubtfully to some member of the paleozoic series; but on the other hand, might with equal or greater probability perhaps be referred to the similar rocks of the Huronian series. These are quite rare, never forming, so far as my observations go, as much as one per cent, of the series. In the several definite enumerations made to determine the percentage of the doubtful specimens, the result never exceeded a fraction of one per cent. In the most extensive enumeration the result was about one-half of one per cent. Aside from these doubtful specimens there are practically no boulders in the belts that can be referred to any of the paleozoic rocks that intervene in the 500 miles between the parent series north of Lake Huron and the tract over which the boulders are now strewn. Occasion-

ally there may be seen erratics from the paleozoic series at or near the surface, but they are not usually so disposed on the surface as to appear to be true members of the superficial boulder tract. There is, therefore, the amplest ground for the assertion that these boulder tracts are of distant derivation, and that they are essentially uncommingled with derivatives from the intermediate region.

3. The boulders of this series are much more angular than those of the typical till sheets. Some of them, indeed, are rounded, but the rounding is generally of the type which boulders derived by surface degradation and exfoliation present. They rarely have the forms that are distinctively glacial. Quite a large percentage are notably angular, and have neither suffered glacial rounding nor spherical exfoliation. Some few are glacially worn and scratched, but the percentage of these is small.

The tracts therefore present these four salient characteristics: (1) the boulders are derived from distant crystalline terranes (400 to 500 miles) and are essentially uncommingled with rock from the intervening paleozoic terranes; (2) they are essentially superficial, and the associated earthy material has a texture differing from that of the subglacial tills; (3) they are notably angular and free from glacial abrasion, except in minor degree; (4) the tracts are so associated with terminal moraines and so related to the topography of the region, that there is no rational ground for doubt that the boulders were borne to their present places by the glaciers that produced the correlative moraines.

In contrast to these superficial boulder formations, the till sheets below are made up of a very large percentage of glacial clay whose constitution shows that it was produced in part by the grinding down of the paleozoic series. In this are imbedded boulders and pebbles that were derived from the paleozoic series as indicated by their petrological character, and, in many instances, demonstrated by contained fossils. While a small part of the boulders contained in the till are angular or but slightly worn, the larger part are blunted, bruised, scratched and polished by typical glacial action. This obvious grinding of the boulders, taken in connection with the clay product resulting from the grinding, affords a clear demonstration that the deposit was produced at the base of the ice by its pushing, dragging, rolling action.

The two formations, therefore, stand in sharp contrast; the one indicating the passive transporting action of the ice in bearing from their distant homes north of the lakes the crystalline boulders and dropping them quietly on the surface, the other indicating the active dynamic function of the ice in rubbing, bruising and scoring the material at its base. The one seems to me a clear instance of englacial and superglacial transportation; the other an equally clear example of subglacial push, drag and kneading.

Now if it were the habit of an ice-sheet of this kind to carry material from its bottom to the surface by internal movement, It would seem that the distance of 400 to 500 miles which intervened between the source of the crystallines and the place of their deposit would have furnished ample opportunity for its exercise, and that there would have been commingled with the englacial and superglacial material many derivatives from the intermediate region, and these derivatives should have borne the characteristic markings received by them while at the base of the ice. The very conspicuous absence of such commingling, and the absence or phenomenal rarity of anything that even looks like such a commingling, appears to me to testify in quite unmistakable terms to the distinctness of the methods of transportation. In view of the great territory over which this particular belt is spread, and the greater territory which is embraced in the other tracts not here specially considered, there is left little ground for doubt

that this distinctness of englacial from basal transportation was a prevailing fact and not an exceptional one. This is supported by concurrent evidence derived from the territory west of Lake Michigan. This territory unfortunately does not bear erratics that have equally distinct characteristics, but, so far as my observation goes, the phenomena are alike throughout. I am therefore brought to the conclusion that, in the interior at least, there was no habitual lifting of boulders from the base of the Ice sheets to the surface, nor any habitual commingling of basal with englacial and superglacial material, except, of course, as it took place by virtue of the falling of the latter through crevasses to the base, and by mechanical intermixture of the two at the edge of the ice. (pp. 52-60)

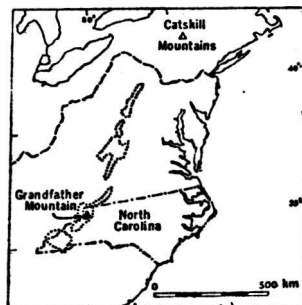
ESD-006 PLEISTOCENE GLACIATION IN THE BLUE RIDGE PROVINCE

Berkland, James O., and Raymond, Loren A.; *Science*, 181:651-653, August 17, 1973. (Copyright 1973 by the American Association for the Advancement of Science)

How extensive was the sheet of ice during the Glacial Period? Periglacial phenomena and evidence such as that presented below suggest we still have much to learn about the Ice Ages—if that is what they were.

Alpine glaciation in the eastern United States has not been reported south of the Catskill Mountains in New York, near 42°N. The Laurentide Ice sheet extended only a short distance south of the Catskills, ending in northern New Jersey and Pennsylvania between 40° and 41°N. The possibility of glacial activity in the Appalachian Mountains south of Pennsylvania apparently has been rejected or ignored by most earlier workers. Even reported periglacial features have been questioned by some Investigators.

Sketch map of the Eastern United States showing the approximate southern limit of the Laurentide ice sheet (dashed lines south of the Great Lakes) . . .



Wayne, Peltier, and Brunnschweller have reviewed the evidence of periglacial conditions extending hundreds of miles south of the Laurentide Ice margin, both in the Appalachians and on the Atlantic seaboard. Evidence of periglacial conditions includes block streams, involutions, conglotturbates, Ice-wedge casts, polygonal soil structures, and frost-thaw basins. Paleontological evidence of a southerly displacement of biotopes includes the following: palynological indications of southern occurrences of white spruce (*Picea glauca*) and fossils of typical boreal animals [for example, musk-ox (*Ovibos moschatus*), caribou (Rangifer *tarandus*), and woolly mammoth (*Mammuthus primigenius*)].

The only previously reported evidence of possible glacial activity in the southern Appalachians consists of striated boulders and cobbles that are locally abundant in Pleistocene river gravels of North Carolina and Tennessee. Although these striated clasts are indistinguishable from glacially striated clasts, their origin has been ascribed to the actions of river ice.

In February 1973, during our investigation of periglacial and possible glacial phenomena on Grandfather Mountain, North Carolina, an outcrop with glacial polish, grooves, striations, and chatter marks was discovered at an elevation of 1370 m in the headwaters of Boone Fork, a tributary of the Watauga and Holston rivers. This occurrence provides the first tangible physical evidence of Pleistocene glaciation in the Blue Ridge Province of the Appalachian Mountains. The glaciated outcrop, at 36°07'N, is 890 km south of any previously known alpine glaciation in the Appalachians and is 350 km southeast of the nearest point reached by the Laurentide ice sheet.

Boone Fork heads west of the town of Blowing Rock, North Carolina, on the northeastern flank of Grandfather Mountain. The headwaters lie in a U-shaped trough having a bedrock floor near an elevation of 1210 m, with enclosing ridges attaining elevations of 1490 to 1810 m. Postglacial mass-wasting processes such as solifluction, slope wash, and debris-avalanches have alluviated the floor of the presumed cirque basin to an estimated depth of 140 m and graded the formerly steep headwall to a gentler angle of 13 deg. Similar mass-wasting on the northwestern side of Grandfather Mountain has produced maximum gradients of 15 to 35 deg. In this area thick unsorted deposits of rock and soil conceal most of the bedrock of the lower slopes. Such deposits, as well as the topography of Grandfather Mountain, suggest that it has reached the stage of late youth in the periglacial cycle of Peltier. Prominent frost-river bedrock pinnacles (tors) give the higher ridges of the mountain a jagged appearance and indicate the lack of maturity of the erosion processes.

The maximum area of the Boone Fork cirque is 1800 by 1400 m, and it narrows eastward to a width of about 800 m in a V-shaped canyon marking the probable eastern limit of ice corrasion. A part of the north-facing slope above this point is covered by a block field (felsenmeer) between elevations of 1290 and 1410 m. This block field, measuring 150 by 360 m, contains jumbled slabs, some as large as 7 m in diameter, of blocky metasandstone of the Precambrian Grandfather Mountain formation. Published records of similar evidence of periglacial activity in the mountains of North Carolina have not previously appeared. However, Michalek has described a number of such features. We expected to find periglacial features in the mountains because Kerr, Eargle, and Bryan had described solifluction phenomena on the Piedmont of the Carolinas, where elevations are much lower.

The preserved glaciated surface in the Boone Fork cirque occurs atop a bedrock exposure on the lower end of a spur that projects from the northern wall of the cirque about 1200 m east of the headwall. The bedrock is arkosic metasandstone and conglomeratic metasandstone assigned by Bryant and Reed to the Grandfather Mountain formation. Foliation in the outcrop strikes N40°W and dips 35°NE. The glaciated surface is considerably weathered, but grooves and

polish are visible on about 5 percent of the top of the outcrop (900 m²). The longest continuous grooves are about 1 m long, 15 cm wide, and 5 cm deep. At least 60 grooves are known and adjacent grooves are parallel, although groove swarms gradually change their trend from S80°E to S40°E from the southern to the northern part of the exposure. This change reflects divergent trends of two lobes of ice which formerly coalesced at the site of the outcrop and preserved it as a bastion. A number of bedrock slopes, oversteepened to 45 to 55 deg. He along the northern and southern edges of the U-shaped valley. These smooth, bare slopes He mainly between elevations of 1430 and 1580 m and they have a striking resemblance to ice-abraded surfaces, although none has been found to exhibit grooves or polish. If these surfaces were Indeed carved by Ice, the maximum thickness of ice in the cirque was about 300 m. The minimum thickness is known to have been at least 100 m, because the grooved outcrop at an elevation of 1400 m is directly above the alluviated valley floor at 1300 m and the alluvium at this point is probably more than 30 m thick.

No moraine was observed at the cirque outlet. However, cirques In the northern Appalachians and elsewhere commonly have little or no morainal debris, and the apparent absence of a moraine here is not considered significant. A probable recessional moraine does appear about 3.2 km north of the Boone Fork cirque along the course of a separate lobe of ice which apparently moved down the canyon of Moody Mill Creek. This stream drains the northern slopes of Grandfather Mountain, and the lower valley bottom is marked by thick deposits of unsorted bouldery debris and a hummocky topography to elevations as low as 970 m.

It would be surprising if positive evidence of mountain glaciation In the southern Appalachians is present only on the northern portion of Grandfather Mountain, but special conditions, make this locality unusual. Erosion has been comparatively slow on the northern flank of the mountain because drainages are graded with respect to the old (Miocene?) surface upon which the Watauga and New rivers flow northward. Immediately south of Boone Fork lies the edge of the Blue Ridge escarpment. The Johns River and other actively downcutting south-flowing tributaries to the Catawba River have been denuding the eastern face of Grandfather Mountain, perhaps destroying completely the evidence of glaciation. Even at Boone Fork It appears likely that the remaining evidence will be lost by erosion within a few hundred years.

Whether or not further proof of alpine glaciation Is discovered in the higher elevations of the southern Appalachian Mountains of North Carolina and Tennessee, the Boone Fork occurrence has important implications. Evidence of alpine glaciation in northern North Carolina suggests a glacial origin for abundant polished and striated boulders in the southeastern states. This alternative to the action of river ice was offered by Wentworth but has been ignored by later investigators. The existence of periglacial features reported In the southern and central Appalachian Mountains, the Piedmont, and the Atlantic coastal plain are strongly supported. A periglacial origin for the Carolina Bays Is brought Into focus. The paleoclimatic and paleobotanical maps of the southern Appalachian area must include local Pleistocene glacial conditions, along with the tundra and boreal conditions suggested by some workers. Finally, the genus of "warm-water walrus" (*Trichechodon*), suggested by Pleistocene fossils from the southern Atlantic states, Is more likely the ordinary circumboreal genus (*Odobenus*). These Arctic animals probably migrated with the cold water that flowed farther south during glacial maxima, as evidenced by the ostracod studies of Hazel.

A favorite target of people dissatisfied with current geological theory, particularly the history of life, is the so-called "thrust fault". George McCready Price, a believer in the literal interpretation of the Bible, maintained that thrust faults did not exist on a large scale and that the story of evolution, as told by the stratigraphic record, was incorrect. This subsection begins with Price's thesis and progresses to various descriptions of thrust faults from the scientific literature. Whether Price has a point is left to the reader; if he does, our whole concept of the planet's history must be revised.

ESI-001 [UPSIDE-DOWN STRATA]

Price, George M. ; Evolutionary Geology and the New Catastrophism, Pacific Press Publishing Association, Mountain View, 1926.

One of Price's favorite geological "anomalies" was the "overthrust fault" used to explain upside-down strata. His attack on the concept of the thrust fault is typical of his style.

But for more extreme cases, say, where Cambrian or other Paleozoic fossils occur on top of Jurassic, Cretaceous, or Tertiary, there is in such a predicament always an anxious search made for faults and displacements; and if others are not to be found, the stratification planes separating the beds are called "faults," and then we are confidently told that immense mountain masses, perhaps covering thousands of square miles, have been pushed up on top of the younger rocks, where they now lie in what looks exactly like a normal position, with nearly horizontal stratification. Albert Heim of Switzerland was perhaps the first to teach the scientific world to speak of huge "overthrust folds," mapping them out with imaginary arcs of circles miles high in the air as the place where these folds once were; and such explanations are not yet entirely discarded. But of late years, the theory of "thrust faults," with the mountains pushed bodily up on top of the other strata, has become the more popular method of explanation, and there is scarcely an artificial geological section made within recent years that does not contain one or more of these "thrust faults," or "thrusts." But the really important thing to remember in this connection is that it is solely because the fossils are found occurring in the wrong order of sequence that any such devices are thought to be necessary,—devices which, as has already been suggested of similar expedients to explain away evidence, deserve to rank with the famous "epicycles" of Ptolemy, and will do so some day.

Here is Geikie's amazing style of argument to prove the reality of such great earth movements:

"We may even demonstrate [?] that in some mountainous ground the strata have been turned completely upside down if we can show that the fossils in what are now the uppermost layers ought properly to lie underneath those in the beds below them."

Some day, I fancy, such a statement will be regarded as one of the curiosities of the history of scientific theories. But this is no isolated expression wrested from its context; it is the fundamental method employed in all modern geological investigation, and well illustrates what Sir Henry Howorth calls the "singular and notable fact that, while most other branches of science have emancipated themselves from the trammels of metaphysical reasoning, the science of geology still remains imprisoned in 'a priori' theories." (pp. 111-112)

ESI-002 HEART MOUNTAIN AND SOUTH FORK DETACHMENT THRUSTS OF WYOMING

Pierce, William G. ; American Association of Petroleum Geologists, Bulletin, 41 591-626, 1957.

The famous Heart Mountain thrust fault in Wyoming has perplexed geologists for many years. The following excerpts from Pierce's paper describe the fault (if that is truly what it is) and illustrate the difficulties encountered in trying to find conventional explanations.

Abstract. In broad outline the Heart Mountain fault of Wyoming is a nearly horizontal thrust whose overriding sheet was derived from a source without any known roots, and whose frontal part has ridden across a former land surface. The suggestion is here made that this thrust and the near-by South Fork thrust are detachment thrusts or decollements, that is, they are sheets of sedimentary rocks which have broken loose along a basal shearing plane, have moved long distances probably by gravitational gliding, and have been deformed independently from the rocks below the fault plane.

The present remnants of the Heart Mountain thrust sheet include more than 50 separate blocks which range in size from a few hundred feet to 5 miles across and which are scattered over a triangular area 30 miles wide and 60 miles long. The rock formations represented in the thrust blocks comprise a very limited stratigraphic range, none being older than the Bighorn dolomite (Ordovician) and none younger than the Madison limestone (Mississippian). The maximum stratigraphic thickness of the formations involved is 1,800 feet, but these include the most competent group of beds in the sedimentary sequence in this area.

In the northwestern part of its known extent the Heart Mountain thrust plane follows the bedding of the rocks and lies at the base of the massive and resistant Bighorn dolomite and above the underlying Grove Creek formation (a thin unit at the top of the Cambrian sequence). Near the center of the area here described this bedding thrust plane changes abruptly to a shear plane that cuts stratigraphically upward across the Bighorn and younger formations; the thrust plane then passes south-eastward onto and across a former land surface. The present thrust remnants on this surface are separated blocks that rest on rocks ranging in age from Paleozoic to Tertiary.

In the area of the bedding thrust the displaced sheet was broken into numerous blocks which became detached from one another by movement, with large spaces or gaps separating them. Thus by tectonic denudation the thrust plane was exposed at the surface. Associated with the events accompanying the thrusting was the rapid formation of a stream channel deposit, here named the Crandall conglomerate. Next there followed the deposition of the "early basic breccia." This blanket is volcanic rock, which is now in the process of being eroded, has preserved much of the geologic record pertaining to the development of the Heart Mountain thrust since middle Eocene time.

The concept is here advanced that, near the close of early Eocene time, the Heart Mountain thrust originated as a detachment or shearing-off of strata at the base of the Bighorn dolomite. Near Dead Indian Hill the advancing south-eastern edge of this bedding thrust sheet passed upward into a shear thrust and thence southeastward onto and across the land surface as an erosion thrust.

The South Fork thrust sheet, which underlies and is slightly older than the Heart Mountain thrust sheet, likewise has the character of a detachment thrust in that the plane of the thrust sheet extends downward to a stratigraphic horizon

in the Sundance formation, but goes no farther. In three test wells which started in the South Fork thrust sheet, the plane of the thrust was found at depths of 550 to 1,040 feet, and the beds below are essentially undeformed.

Characteristic features of the South Fork thrust mass, which suggest a detachment thrust (decollement), are- (1) tightly folded anticlines and synclines and overturned, recumbent, and faulted folds; (2) the base of the thrust mass is in most places at or near a stratigraphic horizon; (3) so far as known, it has no "roots" from which it could have come as a deep-seated thrust; (4) the thrust mass contains no rocks from below the plane of detachment. Although the South Fork thrust mass reacted to deformation quite differently from the Heart Mountain thrust blocks, the differences are readily accounted for by the great lithologic differences of the rocks of the two sheets.

To test further the proposed interpretation for the Heart Mountain and South Fork thrusts, additional field observations should be made to shed more light on the mechanics of the deformation.

Introduction. The writer first began field work in the region of the Heart Mountain and South Fork thrusts in 1935. Detailed field mapping on a scale of 1-31,680 was undertaken, and the work was continued through four succeeding field seasons. The war years then intervened and it was not until 1950 that work was resumed briefly in the area, followed by field work during parts of the summers of 1952, 1953, 1955, and 1956. The present paper presents the structural data bearing on the problem of these two thrusts, obtained during those ten seasons or partial seasons of field mapping.

The Heart Mountain thrust has long been structurally perplexing because there are no known structural roots or source from which it could have been derived. If the thrust had roots and originated as a deep-seated fault in the basement rocks some Precambrian and Cambrian rocks should occur in the thrust sheet, but thus far none has been found. Furthermore, there is no known surface fault or fault zone within or adjoining the region from which the thrust sheet could have been derived, although the possibility can not be eliminated that such a zone exists but is entirely concealed by the volcanic rocks in the Absaroka region.

In broad outline, the structural features of the Heart Mountain thrust are those of a nearly horizontal thrust fault, which in its frontal part has ridden out upon an erosion surface. It has long been recognized, however, that this fault has uncommon features which can not be accounted for by the tectonic movements ordinarily accompanying low-angle thrust faulting. The features which have been observed seem to fit into the structural pattern of a detachment thrust or decollement similar in certain respects to the Jura Mountains of Switzerland. The term decollement (or a shearing-off) as applied by Buxtorf (1916) in the Juras refers to a kind of folding in which a sheet of sedimentary rocks has broken loose or become unglued from the underlying formations and folded independently. The rocks composing the South Fork thrust have folded independently from the underlying beds and thus resemble in that unusual aspect the results of Jura-type tectonics.

The rocks composing the Heart Mountain thrust blocks are not folded but the same basic principle seems applicable, namely, that a sheet of sedimentary rocks has broken loose from the underlying formations and moved independently. Hence, they also are considered as a detachment (decollement).

The term "thrust" as used here is applied without genetic connotation to low-angle faults in which the major component of movement is horizontal in the upper block. Detachment fault, or "detachment along a basal shearing-plane", is a more applicable designation in the genetic sense.

Heart Mountain Thrust. Areal extent.—Remnants of the Heart Mountain thrust occur over a triangular area, about 30 miles wide and 60 miles long, with the apex of the triangle near the northeast corner of Yellowstone Park. The easternmost remnants are at McCulloch Peaks, the southwesternmost are in the vicinity of Sheep Mountain, and the northwesternmost remnants which have been mapped are near Pilot and Index peaks, although reconnaissance examination indicates additional extension to the northwest. About 50 separate blocks have been mapped, ranging in size from blocks only a few hundred feet across to large masses 4-5 miles across.

Rocks composing thrust blocks.—The formations represented in the Heart Mountain thrust blocks cover a very limited stratigraphic range, consisting of Bighorn dolomite, of Ordovician age, Jefferson dolomite and Three Forks shale, of Devonian age, and Madison limestone, of Mississippian age. They have a total stratigraphic thickness of 1,500-1,800 feet. In terms of strength and rigidity, however, they are the most competent group of beds in the entire sedimentary sequence. The Madison, Jefferson, and Bighorn formations are composed almost entirely of limestone and dolomite, largely in massive and resistant beds. Less than 150 feet of the entire sequence is shale, and this occurs mostly in the Three Forks formation. The lower 100 feet or more of the Bighorn dolomite is the most massive and resistant unit in the section.

The rocks in the thrust blocks are cut by a number of high-angle faults. Some of these faults are shown on the map but many can not be shown because of the small scale of the map. Presumably it was movement along these faults, in part at least, which produced angular discordance between the beds above the thrust and those below. Such discordance is observable at many places in the region west and northwest of Dead Indian Hill. Although the normal sequence of the beds above the Heart Mountain thrust, in ascending order, is Bighorn, Jefferson, Three Forks, and Madison formations, in many places this sequence is broken, and one or more of the lower formations may be absent. At Sugarloaf Mountain, for example, Bighorn dolomite forms the base of the thrust block on the north (upper right), but on the south (upper left), the Jefferson dolomite forms the base of the thrust block. Still greater stratigraphic displacement is shown at "Steamboat", where in places Madison limestone forms the base of the thrust. On the north side of the North Fork of Crandall Creek, both faulted and fractured and massive blocks of Madison limestone form the base of the thrust. Were it not for the broken sequence and absence of some formations at places such as these just mentioned, the presence of a fault might not be recognized in the northwestern part of the area. An unusual structural problem, to be discussed later, is posed by this relationship whereby the Bighorn, Jefferson, and Three Forks formations are faulted out of the section. As a generalization with several exceptions, a "normal" section with Bighorn dolomite at the base of the thrust block more commonly occurs where the thrust block is less broken by high-angle faults. The smaller thrust blocks, measuring a few hundred feet across or less, are most commonly Madison limestone.

Tripartite nature of thrust.—The Heart Mountain thrust embodies three types of thrusts: a bedding thrust, a shear thrust (or initial shear thrust), and an erosion thrust (or surface thrust). From the northwest corner of the mapped area southeastward to Dead Indian Creek it is a bedding thrust in which the fault plane follows a very restricted stratigraphic interval—approximately the base of the Bighorn dolomite—and throughout that area the thrust blocks rest on the Grove Creek formation which is at the top of the Cambrian shale and limestone sequence. Between Dead Indian Creek and Dead Indian Hill, the Heart Mountain fault passes from a bedding thrust to a shear thrust, and the rocks underlying the thrust range upward through the stratigraphic succession

from Bighorn dolomite through the Jefferson and Three Forks formations to the Madison limestone. From Dead Indian Hill southeastward it is an erosion thrust, in which the thrust blocks moved over a former land surface, and rest on rocks ranging in age from Paleozoic to Tertiary. A view of two types of the thrust, that is, the bedding and shear thrusts, is shown in Figure 5, in a view looking northward down Dead Indian Creek along the zone of shear thrusting.

The fault contact or fault plane is usually concealed or at best is poorly exposed where it is an erosion thrust or a shear thrust, but the bedding thrust contact is well exposed in places. The fault contact of the bedding thrust may either be clean-cut and sharp, with essentially no brecciation of the beds above or below the fault, as observed at several places, or it may have a zone of broken limestone and limestone debris, such as observed at the northwest end of Sugarloaf Mountain. There the broken limestone zone is about 30 feet thick; its lower contact with the Grove Creek formation is sharp, but its upper contact is indistinct.

In other words, there is little evidence of sliding of one huge rock mass over another.

Structural interpretation. As can be seen from the preceding description, the Heart Mountain thrust is an exceptional feature in several respects, and to account for it requires some new and perhaps unorthodox reasoning and deductions. These might be best presented by first considering the geologic setting at the time of thrusting.

As deduced from the fragments in the Crandall conglomerate, the area encompassed by the bedding thrust had been eroded down to the upper part of the Madison limestone, which formed an immense dip slope, inclined in general toward the southeast. On the northeast, erosion had removed much of the Madison and older sedimentary rocks and in places had reached the Precambrian granitic rocks in the Beartooth uplift. On the east the sedimentary rocks dipped eastward into the Bighorn basin, and successively younger rocks were exposed at the surface farther eastward. The fault and uplift along the eastern edge of the Beartooth Mountains were already of large proportion, as revealed by the record of early Eocene sedimentation. None of the volcanic outpouring of the "early basic breccia" had yet taken place, nor was there to be any until after the emplacement of the Heart Mountain thrust blocks.

It is believed that the areal relationships which have been determined by detailed geologic mapping show that the Heart Mountain thrust consists of three parts: (1) a bedding thrust in the northwestern part of the area that extends southeastward to the vicinity of Dead Indian Creek, where (2) it passes into a shear thrust which rises steeply southeast and emerges along a line extending southwest from Dead Indian Hill, and (3) from this line of emergence it becomes an erosion thrust, wherein the fault blocks continued to move generally south-east.

This picture of fault blocks, separated in some as yet undetermined manner, with the fault plane exposed only briefly in the areas between the fault blocks, seems fantastic if not impossible, but there are several lines of evidence that point to it; if this concept is discarded, several unusual features must be explained, of which the following are particularly significant.

1. What kind of surface does the "early basic breccia" rest on where it is in contact with the Grove Creek formation? In the area of the Heart Mountain bedding thrust are large areas where the volcanic breccia is in contact with a stratigraphic plane yet this contact horizon can not logically be considered an

erosion surface or a plane of intrusion. If it is interpreted as a fault contact, in which both the Heart Mountain thrust blocks and the "early basic breccia" have moved as a unit as postulated by Hares, one would expect an occasional fragment of volcanic rock along the fault contact between the Grove Creek and the overlying thrust blocks of limestone, but such evidence has not been found.

2. A mechanism or process is needed for displacing the sedimentary strata which normally overlie the Grove Creek formation and substituting the "early basic breccia." It is difficult to see how this could be accomplished by fault movement of a blanketing deposit of "early basic breccia," but if it could, and the sedimentary rocks above the Grove Creek limestone and the "early basic breccia" were faulted at the same time as a combined unit, the two units should be intermingled, with fault contacts between them. The areal distribution or relation of units that should prevail if there was such faulting does not occur. The areal pattern exemplified in Figures 7, 9, and 12 seems to require a sequential arrangement whereby a "void" or "tectonically denuded" space is created first.

3. The numerous occurrences of Madison limestone resting on the Grove Creek obviously represent a fault contact, with Three Forks, Jefferson, and Bighorn formations cut out by faulting. What kind of fault movement can be invoked to account for these occurrences? The thrusting of younger beds on older strata is the unusual relationship, in contrast to the common relationship of older beds thrust on younger strata. A method whereby blocks of Madison limestone can here and there be thrust down onto the Grove Creek between fault blocks of Bighorn and Jefferson formations resting on Grove Creek, becomes most difficult if not impossible to explain as long as the fault blocks are in tight lateral contact with one another. However, if the fault blocks become separated, younger rocks from the upper part of a fault block—for example, the Madison limestone—might then move along a previously developed shear or fracture and slide down into the space between fault blocks and come to rest on the Grove Creek formation. The process whereby younger beds could be placed in fault contact with older beds is shown diagrammatically in Figure 19.

ESI-003 THE HIGHLAND OVERTHRUSTS

Gregory, J. W.; Nature, 77:272-274, January 23, 1908.

In some places on earth, older strata are found on top of younger strata, at least according to dating by fossil content. Some writers, such as George McReedy Price, have used these "reversed strata" to question the whole fossil-dating framework. More conventional geologists explain reversed strata in terms of "overthrusts," in which terrestrial forces push older rocks over the tops of younger rocks. Such was the case with the Highland Overthrusts described below. (Price would have ridiculed the explanation given below because of the great dimensions of the overthrust.)

The controversy regarding the structure of the north-western Highlands was a disturbing factor in the progress of geology from 1819, when the problem

was first raised by Maeculloch, until It was closed in 1884 by Sir Archibald Geikie's announcement in Nature (vol. xxxi., p. 29) that the generally accepted view could no longer be maintained. The Nature article—perhaps the most sensational announcement in geological literature—was followed in 1888 by a report from six members of the Scottish Geological Survey giving a summary of the evidence which they had collected as to the structure of the north-western Highlands; and it has taken another twenty years to complete the survey of the whole overthrust region and prepare the detailed observations for publication.

The history of the north-west Highlands controversy is summarised in a chapter by Dr. Home, who lucidly states the results of all previously published geological work on the district. The geological interest of the area dates from the announcement by Maeculloch, In 1819, of his discovery of fossiliferous rocks lying above gneisses, and covered by the gneisses and schists that form the great bulk of the Scottish Highlands. Murchlson, with his keen scent for a good clue, visited the area, and he re-examined it after the discovery by C. Peach, in 1854, of the better fossils (now known to be Cambrian) in the Durness limestones. Murchlson was convinced that the fossiliferous rocks were covered by the eastern gneisses, and, in accordance with the law of superposition, accepted the eastern gneisses as younger than the rocks beneath them. He regarded the fossils as Lower Silurian, and therefore did not shrink from the apparently inevitable corollary that most of the crystalline rocks of the Scottish Highlands are post-Lower Silurian in age. This conclusion had a world-wide influence. Similar crystalline schists form vast regions in all the continents, and they were at first regarded as all pre-Palaeozoic; but if the Scottish schists are altered Palaeozoic sediments, then the similar rocks elsewhere may include rocks of any geological age. To this day vast regions of schists and gneisses are mapped as altered Silurian, In consequence of Murchison's work on the north-west Highlands.

Murchison's views were at once opposed. The common-sense judgment of James Nicol showed him the improbability of Murchison's conclusions, and his keen and careful field-work revealed that the superimposing schists over sediments was not an original arrangement, but was due to subsequent earth movements. The first controversy was short. Nicol's interpretation of the evidence had not the fascinating simplicity of the other theory, and it was not wholly right. The eastern and western gneisses are not simply repetitions of the same series, and Murchison was apparently right In his view that the upper gneisses and schists are an Independent and younger series than the Lewisian gneisses, which underlie the Cambrian band to the west. Moreover, Nicol failed to realise that the apparent bedding planes In the eastern gneisses were not original, but secondary structures due to earth movements.

Murchlson, with a theory attractive by Its charming simplicity and far-reaching results, and right in his recognition of the essential differences between the eastern and western gneisses, swept his critic from the field. Nicol, disheartened by the fate of views which he knew to be essentially correct, practically gave up geological research, and went to his grave, his geology despised and his conclusions rejected—by all except his wife. In 1878, the year before Nicol's death, the controversy was re-opened by that geological knight-errant, Dr. Hicks, who ran a tilt against the Murchisontan theory. It survived his onslaught, but two years later it received an almost fatal blow from Prof. Bonney, who, by work near Loch Maree, demonstrated that some of the rocks of the eastern series were the old Lewisian gneiss brought up by faults. The establishment of this fact, which is described in the memoir as

"the first important advance towards the solution of the problem of the succession in the north-west Highlands since the publication of Nicol's researches" (p. 23), was not enough, although it was supported by the work of Callaway and Hudleston. In 1882-3 Prof. Lapworth mapped in detail the classic sections on the shores of Loch Eriboll; he proved that the apparent sequence was deceptive, and that the eastern gneisses were older than the fossiliferous rocks, and had been placed above them by earth movements; and it was his crowning glory to recognise that many of the fine-grained, shale-like rocks, which look like comparatively unaltered sediments, are the most intensely altered rocks of the area; they consist, like ordinary shales, of fragments of primary rocks, but instead of having been formed by the usual agents of denudation and deposition, they are due to crushing along planes of earth movement.

The close of the controversy was now near at hand. In 1883 Sir Archibald Geikie arranged for the detailed mapping of the Loch Eriboll district by the Geological Survey. The work was soon found to be far more complex than had been expected; it was attacked with invincible patience and thoroughness by the surveyors under Peach and Home; the essential conclusions of Nicol and Lapworth were confirmed, and it was promptly announced in Nature that the Murchisonian theory must be abandoned. In 1888 a preliminary report on the Survey's investigations was published by the Geological Society, but it has taken another nineteen years to extend the survey along the whole of the overthrust line, and to prepare the materials for publication.

The work is of the highest geological importance, and in spite of its necessary descriptive details, every page contains observations of interest. The account of the Torridonian series, for example, describes the oldest considerable land surface known, and some traces of fossils in these pre-Cambrian rocks. The part of most interest is, the account of the movements by which the eastern gneisses have been overthrust on to the younger rocks. The movements have taken place along a line more than 100 miles in length, and have carried the rocks in places for ten miles westward. The thrusting forward of these hard rock slices has produced a most intricate system of faults, and extreme changes in the rocks, some of the fresh structures, as in the pseudo-rhyolites, simulating those of igneous rocks. The extent of the metamorphism is one of the secondary questions of most interest. Its range appears to be very variable; in places the alteration is confined within very narrow limits; elsewhere it may extend to a mile from the plane of movement; but it never appears to be regional, and evidence is given that some of the schists had their present structures before the great disturbances.

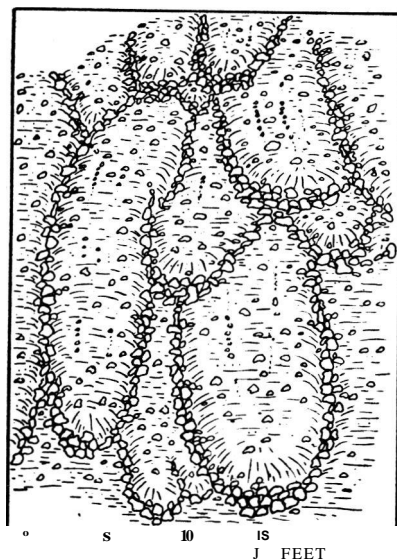
ESP-001 CLASSIFICATION OF PATTERNED GROUND AND REVIEW OF SUGGESTED ORIGINS

Washburn, A. L.; Geological Society of America, Bulletin, 67:823-866, 1956.

Although written rather technically, Washburn's masterful survey includes descriptions of a wide variety of fascinating geological features in which observers recognize some sorts of patterns. These regularities, known only to a few, are so unusual and "out of place" as to deserve mention here. Furthermore, the origin(s) of patterned ground have not yet been explained fully. It is difficult to believe that all the patterns were formed naturally. Could there be a connection with the manmade macroforms presented in the Series M sourcebooks?

Abstract. Patterned ground, which occurs principally in polar, subpolar, and alpine regions, is broadly classified into sorted and unsorted varieties of circles, nets, polygons, steps, and stripes. This descriptive classification and the associated terminology eliminate confusion resulting from the many overlapping and synonymous terms in the literature.

The origin of patterned ground is far from satisfactorily explained. Hypotheses are reviewed and summarized according to dominant processes as follows: (1) ejection of stones from fines by multigelation (often-repeated freezing and thawing), (2) mass heaving, (3) local differential heaving, (4) cryostatic movement (movement by frost-generated hydrostatic pressure), (5) circulation due to ice thrusting, (6) frost wedging, (7) absorption of water by colloids, (8) weathering, (9) contraction due to drying, (10) contraction due to low temperature, (11) contraction due to thawing, (12) convection due to



Sorted steps in till

temperature-controlled density differences, (13) convection due to moisture-controlled density differences, (14) movement due to moisture-controlled changes in intergranular pressure, (15) differential thawing and eluviation, (16) vibration, (17) artesian flow, (18) rillwork (for stripes), (19) solifluction in combination with one or more of the above processes (for stripes).

Conclusions regarding origin are that: (1) the origin of most forms of patterned ground is uncertain; (2) patterned ground is polygenetic; (3) some forms may be combination products in a continuous system having different processes as end members; (4) climatic and terrain interpretation of patterned ground, both active and "fossil", is limited by lack of reliable data about formative processes.

With respect to future research, it is apparent that: (1) laboratory experiments, including cold-room studies specifically dealing with patterned ground, are urgently required; (2) excavations rather than surface observations should be stressed in the field; (3) physicists, pedologists, plant ecologists, and engineers versed in soil mechanics have much to contribute to patterned-ground research, and joint work between them and geologists should produce particularly valuable results.

Definition of Patterned Ground. Patterned ground is a group term for the more or less symmetrical forms, such as circles, polygons, nets, steps, and stripes, that are characteristic of, but not necessarily confined to, mantle subject to intensive frost action.

Patterned ground that is demonstrated to have a distinctive climatic or geographic distribution exclusive of other environments can be designated by appropriate adjectives. Thus, cold-climate patterned ground describes most, but not all, patterned ground.

The term patterned ground was suggested by Washburn because of the following considerations:

The terms Rutmark, Strukturboden, Polygonboden, Polygonenboden, Zellenboden, stone circles, stone rings, stone nets, stone polygons, mud circles, soil circles, mud polygons, soil polygons, fissure polygons, tundra polygons, stone stripes, soil stripes, solifluction stripes and others have all been used to describe features here collectively named patterned ground for want of a satisfactory collective term in English. The term structure ground is awkward, and soil structures is objectionable because it may imply the presence of humus and, as recognized by Sharp, a soil profile, both of which may be absent. Regularity is inherent in the term pattern, and the writer would restrict the use of patterned ground to more or less symmetrical features rather than include phenomena such as stone-banked terraces, rock glaciers, etc. The term patterned ground thus corresponds most closely to the German term Strukturboden as employed by Sorensen although Strukturboden was originally introduced by Meinardus.

The term patterned ground has been widely adopted. The Highway Research Board Committee on Frost Heave and Frost Action in Soil defined the term in connection with patterns resulting from frost action, but the original discussion quoted above did not specify such a limitation, and the occurrence of desiccation patterns very similar to certain patterns attributed to frost action make a narrow definition undesirable. The objection suggested by Black that some types of patterned ground are bedrock forms and not ground in the strict sense of the word does not seem serious in view of the broad use of the term ground (for instance, ground water is not restricted to unconsolidated deposits) and the fact that forms in bedrock are exceptional.

The unit component of patterned ground (excepting steps and stripes)—a circle, polygon, or intermediate form—is here termed the mesh.

Classification of Patterned Ground. Many closely related classifications of patterned ground have been developed, such as those of Meinardus, Høgbom,

Beskow, Huxley and Odell, Steche, Sorensen, and Troll. The writer's classification retains the essential elements of the classifications cited above—pattern, and presence or absence of sorting—and reflects a revised terminology that is orderly and consistent.

A revised terminology is needed. Different terms have been used for similar forms and the same term for dissimilar ones. Stone-polygons, stone rings, and stone nets are a few of the many terms used for stone-bordered polygonal features. The term stone-polygons has also been used to describe almost perfectly circular forms of possibly different origin, called stone circles by Huxley and Odell. Elton used the terms stone-polygons and stone-circles interchangeably in discussing the latter. The use of the name "circular . . . polygon" to distinguish circular from polygonal forms illustrates the problem.

Terminology difficulties also exist regarding forms of patterned ground without a marked stone border. Although the term fissure-polygons is appropriate in places, it is misleading for forms lacking obvious fissures. Moreover, fissures do not necessarily indicate absence of stone borders, for some polygons with fissures have stone borders as well, coincident with the fissures. Elton objected to the term fissure-polygons and suggested mud-polygons, but this term is ambiguous because forms without a stone border do not invariably consist of "mud" but may consist of sand, gravel, or a nonsorted mixture of fines and stones, including boulders. Ice-wedge polygons, tundra polygons, and Taimyr polygons are three synonymous terms where one would suffice.

Elton combined forms with and without a stone border under the group term soil-polygons, but it is misleading to use the term soil, as previously noted, or to refer to obviously circular forms as polygons. A variety of overlapping terms is also used for steplike and striped forms of patterned ground.

Genetic terms such as Brodelboden, based on an unproved mode of origin, are undesirable, as emphasized by Bryan. Clearly it is not yet time for a sound genetic classification of patterned ground, as pointed out by Troll and illustrated by the numerous hypotheses of origin.

Two commonly obvious characteristics of patterned ground that can be ascertained in the field without digging and are also usable in photo-interpretation are: (1) the pattern—whether dominantly circular, polygonal, intermediate (nets), steplike, or striped, (2) the presence or absence of obvious sorting between stones and fines. The following classification, based on Washburn, combines the two characteristics. The arrangement of the classification is in the direction of increasing gradient; thus most circles, nets, and polygons occur on essentially horizontal ground, and steps and stripes are limited to slopes. Where steps and stripes occur together the latter are on the steeper gradient.

Circles

Sorted (including debris islands)

Nonsorted (including peat rings, tussock rings)

Nets

Sorted

Nonsorted (including earth hummocks)

Polygons

Sorted

Nonsorted (including frost-crack polygons, ice-wedge polygons, tussock-birch-heath polygons, desiccation polygons)

Steps

Sorted

Nonsorted

Stripes
 Sorted
 Nonsorted

As pointed out by Black some patterned ground forms are gradational in pattern and sorting. With respect to patterns, some sorted circles grade into sorted polygons, and some sorted polygons merge into steps and stripes. There seems to be a similar gradational series with nonsorted forms of patterned ground. With respect to sorting, transitional types have been reported between sorted and nonsorted circles and between sorted and nonsorted polygons. Thus, in places it is difficult to classify a given form, but most classifications involve the same problem. A single broad heading may include similar forms of differing origin, but the only solution to this difficulty is a sound genetic classification, which requires more knowledge of formative processes than is now possessed.

The writer believes that the use of the simple descriptive terms of the present classification, supplemented by qualifying adjectives, such as miniature, large, sandy, silty, or clayey, and by detailed quantitative descriptions where necessary, will help develop a sound genetic classification. The terminology of the present classification is not intended to supplant existing terms, such as ice-wedge polygons, peat rings, tussock rings, tussock-birch-heath polygons, and any other appropriate descriptive or genetic terms that can be used in a unique sense.

The following definitions are reworded and formalized from Washburn except where otherwise noted. References given for synonyms clarify the sense in which a term has been used and generally, but not necessarily, include the first use.

Sorted Circles. Definition: Sorted circles are patterned ground whose mesh is dominantly circular and has a sorted appearance commonly due to a border of stones surrounding finer material. Depending on usage, more or less synonymous terms may include those listed below for sorted polygons and, in addition, stone circles, Steinringe, Meinardus, Brodelboden, and others.

Debris islands are sorted circles occurring amid blocks or boulders. This term is here used for the first time, although it is essentially a translation of the German synonyms, Erdinseln and Schuttinseln (earth islands and debris islands).

Form and size: Sorted circles form singly or in groups and where crowded closely together may be difficult to distinguish from sorted polygons. (Cf. sorted nets.) Vegetation if present does not usually emphasize the pattern as strongly as in nonsorted forms. In Svalbard where sorted circles are classically developed they vary in diameter from 0.8 to over 3 m. Miniature sorted circles within larger sorted forms have been described.

Debris islands are generally isolated forms but according to Hamberg they may also be grouped. Hamberg reported diameters of about 1 m.

Constitution: The stones in the border around the central area of finer material may range from pebbles in miniature sorted circles to boulders in large ones. The finer material may grade into or abut sharply against the border. The central areas of most sorted circles contain abundant fines, but some consist of gravels largely free of fines, at least at the surface. In any one area the size of bordering stones commonly increases as depth and breadth of the stone borders increase; Meinardus and Poser indicated that in general the size of bordering stones increases with the over-all size of a form. The diameter of a form may reflect depth of sorting in some places, but not in others: Paterson described a large sorted circle with stones up to a foot across

resting almost directly on underlying rock. On the whole, sorting and distribution of rock particles in sorted circles is similar to that in sorted polygons, although less information on circles is available in the literature. Involute structure in small sorted circles has been reported.

Debris islands consist of more or less isolated patches of fines surrounded by boulders or blocks. Small stones were present among the fines in the descriptions noted.

Occurrence: Sorted circles are characteristic of polar environments, but some forms occur also in subpolar and alpine regions. Circles may develop on mantle derived from subjacent bedrock or on transported mantle. Permafrost is present where sorted circles are best developed but apparently is not necessary for their formation; in Iceland, where permafrost is sporadic, some sorted circles are reported where it is absent.

Debris islands have been reported from polar, subpolar, and alpine environments. They characteristically occur in block or boulder rubble, and some of the descriptions associate them with slopes. Meinardus recognized this association although he pointed out that the surface of a debris island is approximately horizontal. Debris islands may occur also on essentially horizontal surfaces. Paterson reported a "circular shingle polygon", which appears to be a debris island whose "convex mud centre" was not over 15 cm (6 inches) thick with bordering stones resting almost directly on rock. Some debris islands, as on Victoria Island, occur in areas of permafrost.

Nonsorted Circles. Definition: Nonsorted circles are patterned ground whose mesh is dominantly circular and has a nonsorted appearance due to the absence of a border of stones such as that characterizing sorted circles.

More or less synonymous terms are spot-medallions and cemetery hummocks, mud circles, frost scars, peat rings, and tussock rings.

Form and Size: Nonsorted circles, like sorted circles, develop singly or in groups. Vegetation is a characteristic element in outlining the pattern. Many isolated non-sorted circles form relatively bare spots amid vegetation; grouped circles commonly have borders of vegetation separating the individual circles. In places the bordering vegetation forms a ridge, ranging 20-90 cm (8-36 inches) high in peat rings described by Hopkins and Sigafos. Other nonsorted circles lack a distinct ridge. Dimensions are similar to those of sorted circles. Rousseau reported diameters of 0.5-2 m, and Poire gave comparable dimensions. The "frost scars" of Hopkins and Sigafos varied "from a few inches to several tens of feet in maximum diameter" and their peat rings and tussock rings, from 1.2 to 3.7 m (4-12 feet) across. Well-developed nonsorted circles tend to have central areas that are distinctly domed, the local relief varying in tussock rings from 7.5 to 15 cm (3-6 inches) to about 1 m. Miniature nonsorted polygons occur on some of the dome areas.

Constitution: Nonsorted circles (peat rings) studied by Hopkins and Sigafos ". . . consisted of silt with a little sand and a few pebbles but contained no rock fragments more than 3 inches in largest dimension". The forms described by Washburn consisted also of fines, but with numerous stones. According to Hopkins and Sigafos, bare spots such as nonsorted circles should have a high ice-lens content compared to surrounding vegetation-covered ground—a relationship confirmed by D. G. Mac Vicar, Jr. for nonsorted circles in the Chandler Lake area of northern Alaska. Cross sections developed by Hopkins and Sigafos demonstrate that involutions are common subsurface features.

Occurrence: Nonsorted circles occur mainly in polar, subpolar, and alpine environments, but circles similar in pattern occur elsewhere as in subhumid and semiarid areas in Australia where they are known as "normal gilgai". Most nonsorted circles are confined to essentially horizontal surfaces. Permafrost is believed by Hopkins and Sigafos to be associated necessarily with the peat

rings and tussock rings they studied. "Fossil" forms of nonsorted (and perhaps sorted) circles may be represented by involutions in some stratigraphic sections.

Sorted Nets. Definition: A sorted net is patterned ground whose mesh is intermediate between that of a sorted circle and a sorted polygon and has a sorted appearance commonly due to a border of stones surrounding finer material. The term was defined by Washburn. "Net" as in stone nets is common in patterned-ground literature.

Discussion: Except for pattern, sorted nets resemble sorted polygons. The term provides a convenient pigeonhole for forms with a mesh that is neither dominantly circular nor polygonal; obviously it would be difficult and misleading to classify such forms as either circles or polygons. Thus, Antevs described mesh patterns that ranged from a well-defined polygonal to "nearly round" or "circular" shape. Troll, also, illustrated forms that could be described as sorted nets because of their intermediate pattern. Since accurate recognition of patterns is probably an essential element in determining the origins of patterned ground, the term sorted net should not be used indiscriminately but should be restricted according to the above definition.

Nonsorted Nets. Definition: A nonsorted net is patterned ground whose mesh is intermediate between that of a nonsorted circle and a nonsorted polygon and has a nonsorted appearance due to the absence of a border of stones such as that characterizing a sorted net. This term is here used for the first time.

Discussion: Except for pattern nonsorted nets resemble nonsorted polygons although some nonsorted polygons (including many ice-wedge polygons) have a mesh larger than that of any nonsorted net. Again, the term is a convenient pigeonhole for forms that are difficult to classify and should be restricted to such forms. An example is cited from arctic Canada. Hopkins and Sigafos described closely spaced nonsorted circles ("frost scars") as evolving into tussock-birch-heath polygons; presumably such an evolution should produce intermediate patterns that would also be difficult to classify as either circles or polygons.

Earth hummocks are a particular type of nonsorted net with a mesh characterized by a three-dimensional knoblike shape and cover of vegetation. The term earth hummocks is derived from Sharp. More or less synonymous terms are thufur, Bulten, Hugelboden, Rasenhugel. Palsen are large earth-hummock-like features typical of parts of Scandinavia and Siberia.

Earth hummocks form in groups rather than singly. Earth hummocks in Iceland are 25-50 cm high and 1-2 m in diameter. Sharp observed similar dimensions in Canada although he noted that forms on hillsides tended to be elongate across the slope. The Icelandic earth hummocks consist of a clay (Ton) or loam (Lehm) interior covered by peat and by vegetation composed of grasses and mosses, acid in reaction. In the Canadian forms described by Sharp, "The hummocks consist of an earthen core with a 3- to 6-inch hull of humus, moss, and plant roots. The plants on top of the mounds are chiefly grass and small bushes with grass and moss predominant in the low damp areas between." Earth hummocks are probably most common in subarctic and alpine environments, but Troll cited some arctic occurrences, including Nieland's observations in Greenland. Earth hummocks are apparently best developed on more or less horizontal surfaces. Thoroddsen reported they do not occur on mountain sides in Iceland. However, according to Sharp, "Well-developed hummocks are common on slopes up to 20 degrees. They do not form on much steeper slopes. . . ." where he observed them in Canada. Although earth hummocks are almost certainly related to frost action, their prevalence in Iceland, where permafrost is sporadic, and particularly in the southern coastal region, where permafrost is absent, indicates that earth hummocks are not

necessarily associated with permafrost.

Sorted Polygons. Definition: Sorted polygons are patterned ground whose mesh is dominantly polygonal and has a sorted appearance commonly due to a border of stones surrounding finer material.

Depending on usage, more or less synonymous terms may include stone-polygons, stone rings, stone nets, Polygonenboden-Typus I, Steinnetze or Steinnetzwerk, and others.

Form and Size: In contrast to circles, sorted polygons apparently never develop singly. As with sorted circles, vegetation if present does not in most places emphasize the pattern as strongly as it does in nonsorted forms of patterned ground. According to Steche sorted polygons range in size from a few centimeters in diameter to large forms 10 meters across, with the size tending to increase with increasing severity of climate and availability of water; however, miniature forms may occur in vegetation-free central areas of large forms as well as independently.

Constitution: Size range and sorting of stones and fines in sorted polygons are similar to sorted circles, although Ahlmann indicated that the largest stones are not necessarily associated with the largest polygons. The central area of a sorted polygon may appear to consist almost entirely of fines but closer inspection may reveal a number of stones. Like sorted circles, some sorted polygons develop in gravel. Especially in large polygons, tabular stones of the borders tend to be on edge and oriented parallel to the border. The stony borders of many sorted forms, including nets, narrow downward. Other borders widen with depth, suggesting that distinct types may be involved as indicated by Poser. Lundqvist reported that stones within the central areas of sorted polygons tend to show a preferred orientation with the long axes transverse to the nearest border, the exact angle possibly influenced by other near-by borders.

Occurrence: Sorted polygons are characteristic of polar, subpolar, and alpine environments. They are much more widespread than sorted circles. According to Huxley and Odell they occur ". . . apparently rarely (at least when well developed) on perfectly level ground"; further observations are desirable with respect to this question. "Fossil" forms have been recognized from regions that were subjected to a more severe climate during the Pleistocene. As with circles, polygons occur on mantle derived from the subjacent bedrock or on transported mantle. Permafrost is not necessarily associated with miniature sorted polygons but is present where large sorted ones are best developed. A peculiar sorted polygonal form from Christmas Island in the Pacific Ocean and sorted polygonal patterns from the Libyan Desert illustrate the fact that sorted polygonal patterns are not confined to polar, subpolar, or alpine environments.

Nonsorted Polygons. Definition: Nonsorted polygons are patterned ground whose mesh is dominantly polygonal and has a nonsorted appearance due to the absence of a border of stones such as that characterizing sorted polygons.

Depending on usage, more or less synonymous terms may include fissure-polygons, mud-polygons, contractional polygons, Polygonboden, Polygonenboden-Typus II, Zellenboden, and others.

Tussock-birch-heath polygons, vegetation polygons and frost-crack polygons, ice-wedge polygons, and desiccation polygons are special varieties of nonsorted polygons.

Ice-wedge polygons are nonsorted polygons characterized by bordering ice wedges. Tundra polygons and Taimyr polygons are synonyms for ice-wedge polygons, but Steche and Troll have objected to the term tundra polygons, and the name Taimyr polygons implies a too limited geographic restriction. Polygons without ice wedges that have a surface appearance practically identical to ice-wedge polygons but may be of different origin have been described. Obviously such forms, and other nonsorted polygons in which the presence or

absence of ice wedges is not established, should not be termed ice-wedge polygons, as recognized by Hopkins, Karlstrom, et al. in their use of the term frost-crack polygons for somewhat similar forms not necessarily associated with permafrost.

Form and Size: Like the sorted variety, nonsorted polygons apparently never develop singly. The borders are commonly but not invariably marked by obvious fissures in the ground. Vegetation if present is generally concentrated along the borders and emphasizes the polygonal pattern, especially in large forms. Nonsorted polygons range in diameter from a few centimeters to many meters. Commonly the small ones have a pentagonal or hexagonal mesh and lack ice wedges. Small nonsorted polygons occur in the central areas of some larger sorted and nonsorted polygons. Tussock-birch-heath polygons are characterized by the vegetation assemblage indicated and have a diameter range of 2.1-4.6 m (7-15 feet) except where drawn out on a slope.

Ice-wedge polygons are typically large. Although diameters as small as 1-3 m have been reported, and 4.6 m (15 feet) is not uncommon, the average size is larger. Steche cited a diameter range of 10-40 m and Troll a range of 15-20 m. Black has given maximum diameters of 100 m or more. The pattern tends to be tetragonal, but pentagonal and hexagonal forms occur also; Schenk suggested that the tetragonal forms are characteristically associated with inclined surfaces, but detailed data are lacking on this point. The borders may be either ridges or depressions, giving rise respectively to low-centered or high-centered ice-wedge polygons.

Constitution: Nonsorted polygons may consist of silt, sand, or gravel, or of a nonsorted mixture of fines and stones. Vegetation is an essential element of some types, such as the tussock-birch-heath polygons described by Hopkins and Sigafoos and the vegetation polygons of Hopkins, Karlstrom, et al. Because nonsorted patterned ground is common in uniform mantle, and sorted forms can develop only in mantle consisting of rock particles of various sizes, it has been suggested that each of these types of patterned ground is restricted to the mantle type indicated. This conclusion is erroneous, for as indicated above nonsorted polygons may consist of a nonsorted mixture of fines and stones. The borders of nonsorted polygons are commonly characterized by wedge-shaped fissures narrowing downward. In places tabular stones lie parallel to the fissure sides, reflecting the wedge shape of the fissure. In ice-wedge polygons the bordering fissures, whether in ridges or depressions, are underlain by an irregularly wedged mass of more or less clear ice. Cross sections show that beds adjacent to ice wedges may be contorted and upturned. Involutions are common in the tussock-birch-heath polygons studied by Hopkins and Sigafoos.

Occurrence: The occurrence of most nonsorted polygons is similar to that of sorted ones. Under special conditions nonsorted polygons occur on appreciable slopes; Longwell described polygonal "slope mudcracks," Roscoe reported large nonsorted polygons on steep slopes in the Antarctic, and the present writer has seen small forms 15 cm across on a sandy slope of 27° in Greenland. Evidence has been cited frequently for "fossil" forms, especially ice-wedge structures, from temperate regions formerly subjected to a more severe climate. As with sorted polygons, permafrost is not necessary for the formation of most small forms, although it appears essential for the tussock-birch-heath variety described by Hopkins and Sigafoos. Permafrost is always present with ice-wedge polygons. The fallacy of assuming that the formation of all forms of patterned ground, especially nonsorted polygons, is confined to polar, sub-polar, or alpine regions is demonstrated by desiccation polygons in temperate and arid regions, by Lang's and Knechtel's description of nonsorted polygons 24.5-27.5 m (80-90 feet) in diameter in Animas Valley, New Mexico, and by

the recent formation in Poland of nonsorted polygons 1.5-3 m in diameter, attributed to desiccation, which are very similar to arctic forms. As with other types of patterned ground, almost all nonsorted polygons are associated with mantle material. Yet an unusual type has been described in which intensive frost wedging along the joints of polygonally jointed, flat-lying bedrock developed a pronounced polygonal pattern at the surface.

Sorted Steps. Definition: Sorted steps are patterned ground with a steplike form and a sorted appearance due to a downslope border of stones embanking an area of finer material upslope. This term is here used for the first time.

Depending on usage, more or less synonymous terms may include stone semicircles, stone-banked terraces, stone garlands, Steinguirlanden, and others.

Antevs considered stone garlands and stone-banked terraces synonymous but Sharp regarded them as two closely related types. The forms described by Antevs are generally larger, more terracelike, and more irregular than sorted steps. But because the forms described by Sharp as stone garlands are more or less regular, clearly transitional between sorted polygons and sorted stripes and therefore a type of patterned ground, they are here regarded as sorted steps. The term terracette, which was considered in place of step, is pre-empted, and the term garland has been used for a wide variety of features. Thus, terms such as stonebanked terraces and stone garlands should be reserved for terrace-like features that lack a more or less regular pattern and are not well-defined forms of patterned ground.

Form and Size: Sorted steps form in groups, rarely if ever singly. Vegetation if present does not generally emphasize the pattern as strongly as in the nonsorted forms. The steps described by Sharp are 1.2-2.4 m (4-8 feet) wide, parallel to the contour, and up to 7.6 m (25 feet) long in a downslope direction: the stone borders are most pronounced at the downslope end where they form distinct embankments. These embankments or risers are convex downslope, and the steps appear to overlap and intersect. The steps grade upslope into sorted polygons and downslope into sorted stripes.

Constitution: The treads of the sorted steps described above consisted of gravelly sand, silt, and clay within stone borders that contained boulders up to 0.3 m (1 foot) in diameter. Tabular stones in the borders were commonly on edge; they were oriented vertically along the lateral margins and dipped upslope at angles of 60°-70° in the risers.

Occurrence: Sorted steps seem to have the same general occurrence as sorted polygons and sorted stripes, except that they are characteristic of moderate slopes, transitional between the essentially horizontal surfaces commonly associated with circles or polygons and the steeper slopes associated with stripes. Sharp recorded sorted steps on slopes of 5°-15°, but the treads had only a 2- to 3-degree inclination downslope.

Nonsorted Steps. Definition: Nonsorted steps are patterned ground with a steplike form and a nonsorted appearance due to a downslope border of vegetation embanking an area of relatively bare ground upslope. This term is here used for the first time.

Depending on usage, more or less synonymous terms may include turf-banked terraces, Terrassenboden, and others. Many of the comments made on the terminology of sorted steps apply in a general way to nonsorted steps. Thus, terms such as turf-banked terraces and turf garlands should be reserved for irregular, terracelike features that are not clearly defined forms of patterned ground; such features are probably far more common than nonsorted steps.

Form and Size: Nonsorted steps, like sorted steps, form in groups and have lower borders (risers) that tend to be convex downslope. Vegetation is a characteristic element in outlining the pattern. The nonsorted steps described by

Sharp differed from adjacent earth hummocks, grading back into the hill slope instead of having an intervening depression. These steps were approximately the same size as the earth hummocks, i. e., 0.3-0.6 m (1-2 feet) high with ground-plan dimensions of 0.3-1.5 m (1.5 feet).

Constitution: The absence of stone borders, such as those characterizing sorted steps, is an essential feature of nonsorted steps. The nonsorted steps of Sharp consisted of an earthen core with a 7.5-15 cm (3-6 inch) hull of humus, moss, and plant roots. Where this vegetation was lacking on the upper surface of steps there was stony soil.

Occurrence: Apparently nonsorted steps have the same general occurrence as earth hummocks but are confined to slopes. Because earth hummocks need not be associated with permafrost, it is probable that nonsorted steps, too, may occur without it.

Sorted Stripes. **Definition:** Sorted stripes are patterned ground with a striped pattern and a sorted appearance due to parallel lines of stones and intervening strips of dominantly finer material oriented down the steepest available slope.

More or less synonymous terms are soil stripes, stone-bordered strips, striped ground and striped soil, stone-stripes, earth stripes, rock stripes, Streifenreifen and Steinbänder, Streifenboden, and others.

Form and Size: Sorted stripes never form singly; they are essentially parallel and may be sinuous. Vegetation if present does not usually emphasize the pattern as strongly as in nonsorted stripes. The width of individual stony stripes ranges from a few centimeters to 1.5 meters (5 feet) or more, and the intervening stripes of finer material may be two or four times wider, according to Sharp. Sharp also reported that he was able to trace individual stripes continuously for several hundred feet.

Constitution: In sorted stripes the stones range from pebbles in miniature stony stripes to boulders in large ones. The intervening stripes of finer material, in many places poorly sorted, may also contain stones. Tabular fragments in the stony stripes may be on edge and oriented parallel to the stripes. The depth of sorting tends to vary with the size of the forms, as in sorted polygons and sorted circles, extending to a depth of 0.6-0.9 m (2-3 feet) in the forms observed by Sharp. The stony stripes commonly narrow downward in vertical section, and in places the stones become smaller in the same direction. A cross section by Sharp suggests that, as with sorted polygons, this downward narrowing is not universal.

Occurrence: Except for being confined to slopes, sorted stripes commonly have the same occurrence as sorted polygons. Sorted polygons may merge into sorted stripes through a transition gradient of approximately 3° - 7° , and sorted steps may occur as transition forms. Some sorted stripes, however, occur without associated sorted polygons. Maximum slopes on which sorted stripes have been reported vary from 15° to 30° . As with sorted polygons, large sorted stripes commonly occur with permafrost, although small ones may occur without it. The small sorted stripes described by Poser from the vicinity of Reykjavik, Iceland, are located in permafrost-free ground. Because sorted stripes are slope phenomena they are probably rarely preserved in "fossil" form in stratigraphic sections, although such forms have been reported by Ducker and Norvang.

Nonsorted Stripes. **Definition:** Nonsorted stripes are patterned ground with a striped pattern and a nonsorted appearance due to parallel lines of vegetation-covered ground and intervening strips of relatively bare ground oriented down the steepest available slope.

A synonymous term is solifluction stripes, but since solifluction is also associated with sorted stripes, the term nonsorted stripes is preferable. The designation vegetation stripes has been used both as a synonym and as a term

for sorted stripes emphasized by vegetation.

Form and Size: Nonsorted stripes resemble sorted stripes, but vegetation is a characteristic element in outlining the pattern. Nonsorted stripes have not been extensively discussed in the literature. One report from arctic Canada states that vegetation occupied slight depressions similar to the bordering depressions of nonsorted polygons that occurred on nearly level ground immediately upslope. These stripes of vegetation were discontinuous and were 0.3-0.6 m (1-2 feet) wide and spaced 3-4.6 m (10-15 feet) apart. Elsewhere, the alternating stripes of vegetation and bare ground were about equally wide. Nonsorted stripes have also been described by Poser.

Constitution: The absence of lines of stones, such as those characterizing sorted stripes, is an essential feature of nonsorted stripes. The nonsorted stripes discussed above and others in the same area consisted of a nonsorted mixture of fines and stones, as did Poser's, except for a concentration of stones in places at the surface. The stripes of vegetation are commonly wedge-shaped in vertical section and narrow downward. This relationship was also noted by the writer in the vicinity of Holman Island Post, Victoria Island.

Occurrence: Allowing for the difference in slope, the occurrence of nonsorted stripes is presumably about the same as for nonsorted polygons. That patterns resembling typical nonsorted stripes are not confined to polar, sub-polar, or alpine regions is demonstrated by "wavy gilgai" in various parts of Australia. As with sorted stripes, preservation of "fossil" nonsorted stripes in stratigraphic sections is probably exceptional.

The Problem of Patterned-Ground Origin. Despite the voluminous literature on patterned ground, very little is established about its genesis, and it is hoped this review will help investigators to focus on the critical elements of the many problems involved. A polygenetic origin is stressed by several investigators, including Poser who decided that no one hypothesis could explain the variety of forms that exist. The present review of the many hypotheses that have been suggested supports the polygenetic concept, which, in order to explain all forms of patterned ground, implies multiple processes or multiple facets of a complex process such as frost action. As suggested in more detail in the conclusion, the writer favors the view that a complete explanation involves processes and forms that are end members of a continuous system having combination processes and forms as intermediate products.

At this point Washburn devotes 20 pages to the survey and documentation of the various hypotheses of origin. These are summarized very nicely in his conclusions.

Conclusions. The descriptive classification of patterned ground adopted in this paper eliminates ambiguities and confusion resulting from the many overlapping and synonymous terms that have appeared in the literature. The classification is based on geometric pattern and presence or absence of sorting, and its main classes comprise sorted and nonsorted varieties of circles, nets, polygons, steps, and stripes. In the absence of more data on the genesis of the forms involved, any comprehensive classification but a purely descriptive one is believed to be impractical and premature.

The preceding discussion of hypotheses and processes supports the conclusion of Poser and others concerning the polygenetic origin of patterned ground. Although this conclusion is not new, it is here fully documented. Thus, the writer believes that any over-all explanation must involve separate processes, with frost action being regarded as a complex of processes that are highly important but not the only ones represented. Not only are many different types of patterned ground involved, but it seems probable that somewhat similar forms may originate by quite different processes. Another and obvious conclu-

sion is that the genesis of the various kinds of patterned ground is far from established.

In polygonal patterns, it is certain that some meshes are products of drying, and very probable that others result from contraction due to low temperature. The writer believes that both types occur in cold climates and that some meshes may be combination forms reflecting the operation of both processes. In the case of circular patterns, the evidence indicates that probably local differential heaving and perhaps cryostatic movement are genetic processes of widespread significance. Possibly these processes, too, complement each other in complex fashion. For instance, cryostatic movement could bring saturated fines adjacent to coarser material with the result that the fines might be subjected to intense local heaving.

With respect to sorting, ejection of stones toward freezing surfaces by multigelation, their movement by gravity, and eluviation of fines may be key processes. They do not explain polygonal, circular, or striped patterns as the above-mentioned processes may but they are associated with these processes and may determine whether sorted or nonsorted forms are produced if other conditions remain equal.

Solifluction is probably of major significance in the origin of patterned ground on a slope. Presumably it combines with one or more of the other processes to produce the various types of patterned ground that are confined to slopes.

It is tempting to speculate that desiccation, contraction due to low temperature, local differential heaving, and cryostatic movement may combine to form a single continuous system responsible for both polygonal and circular patterns. Geometrically the end members could be represented by the corners of a tetrahedron, and the combination patterns by intermediate positions. Such intermediate positions might account for some nets, which according to the usage in this paper are neither dominantly circular nor polygonal. If to these pattern-forming processes are added ejection of stones, their movement by gravity, and eluviation as sorting processes, and solifluction as the key modifier of patterns on a slope, elements of a comprehensive explanation of patterned ground are at hand. Whether or not these processes turn out to be the key ones, the writer predicts that a complete explanation of patterned ground will involve several specific processes arranged in a similar model.

Of the remaining processes reviewed, the writer believes that in the absence of additional evidence, circulation due to ice thrusting and convection due to temperature-controlled density differences can be eliminated from further consideration in the origin of patterned ground. Frost wedging, weathering, artesian pressure, and rillwork are probably valid genetic processes in special situations but not of widespread significance. The writer regards all the other reviewed processes as speculative but nevertheless stimulating in the light of present inadequate knowledge.

Before the origin of patterned ground is fully understood and the climatic significance and interpretation of present-day and "fossil" forms correctly established, it will be necessary to have much more detailed and accurate information than is now available. Cold-room studies, field observations of subsurface phenomena at different times of the year, and cooperative work between geologists, physicists, soil engineers, pedologists, and plant ecologists are urgent desiderata in further research.

ESP-002 THE HINGHAM RED FELSITE BOULDER TRAIN

Howe, Oliver H.; Science, 84:394-396, October 30, 1936.

In the northern part of the town of Hingham, Massachusetts, is an area of banded red felsite, fragments of which were carried away by the ice-sheet and deposited in a fan-shaped boulder train that extends southeastward for many miles. In 1904 Professor W. O. Crosby published a map of part of this train extending about six miles from its source. For many years the writer has been mapping the locations of several hundred specimens of red felsite found by him within eight miles of the source. In 1933 two were found in a distant part of Marshfield and later search has revealed others on Cape Cod, Martha's Vineyard and Nantucket, to a maximum distance of eighty-five miles from the source.

As long ago as 1833 Professor Edward Hitchcock found bold outcrops of this rock, which he described "as in the form of ridges." In 1904 Professor Crosby mapped three neighboring ledges, two of which have since disappeared. The only remaining one is small in area and does not stand above the ground surface. There are, however, in that vicinity long walls and ornamental gate posts built entirely of the red felsite.

The rock, which has been called by some geologists the most beautiful in Massachusetts, is deep red to purple, compact and almost flinty, and contains scattered, dull yellow lenticular masses about half an inch long. Weathered surfaces show a distinct flow-structure marked by parallel thin discontinuous sheets or flat lenses of compact red material in a gray or pinkish matrix that is shown by a lens to have a similar flow-structure but on a much smaller scale. Abundant small phenocrysts of quartz and a few larger ones of feldspar are scattered in an aphanitic ground-mass, but there are no other distinguishable minerals. The exact sort of rock has not been determined microscopically but it is probably a rhyolite or a dacite. As it contains small fragments of rocks of other sorts as well as of the red felsite itself, it is clearly a flow-breccia. It is not much roughened by weathering, but the dark portions are often left in relief, and it is easily distinguished from other rocks. It was one of the favorite materials used by the Indians in making arrow and spear heads.

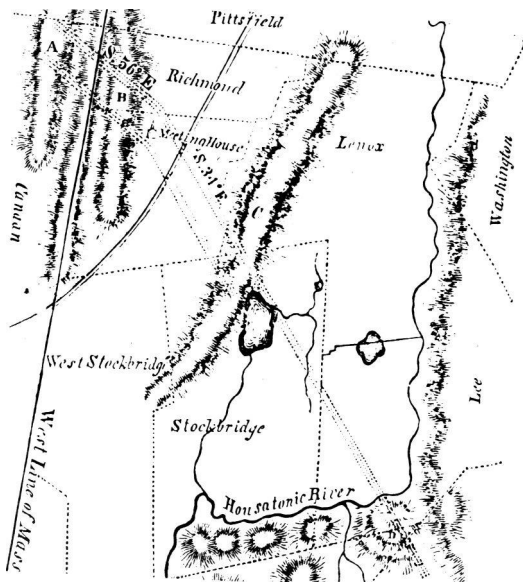
The margins of the boulder train diverge south-eastward, the angle between them being about 60°. The northern margin reaches the coast in about ten miles, at the entrance to Scituate Harbor, south of which place specimens of the red felsite are abundant in the drift, but none have been found north of a line drawn from the source of the boulders to the harbor entrance. The western margin reaches Vineyard Sound in Falmouth, fifty miles from the starting point. Specimens of red felsite were found in abundance along the western margin and to the east of it, but none west of it either on the surface or in the numerous gravel pits seen in the first eighteen miles south of the source of the train.

If the lines delineating the margins of the fan be prolonged southeastward, the area between them will include all Cape Cod, all Nantucket and the adjacent islands and the eastern half of Martha's Vineyard. It is interesting to note that the part of that island in which fragments of red felsite have been found is the part that was occupied by the Cape Cod Bay lobe of the ice-sheet at its greatest extension, and that the Buzzard's Bay lobe which deposited the moraine in northwestern Martha's Vineyard did not carry any of the Hingham red felsite. The western margin of the boulder train reaches the Vineyard about two miles westward of West Chop, the northernmost point of the island, in the interlobate moraine.

ESP-003 PATTERNED GROUND

..The western boundary, according to specimens found, is a consistently straight line and apparently marks the boundary of the fan-shaped train in the early stages of glaciation, and also approximately the boundary between the lobes of the ice-sheet at that time.

Farther east a moraine, of which the Manomet Hills of Plymouth are salient features, is plainly an interlobate moraine dividing the two lobes in the last stages of glaciation. This moraine begins with the hills of Marshfield and continues with the Manomet Hills, which extend southward nearly to the Cape Cod Ship Canal. South of the canal a distinct moraine extends as far as Woods Hole. On Martha's Vineyard the original boundaries seem to have prevailed.



*The boulder trains
described in ESP003*

ESP-003 DESCRIPTION OF A SINGULAR CASE OF THE DISPERSION OF BLOCKS OF STONE CONNECTED WITH DRIFT, IN BERKSHIRE COUNTY, MASSACHUSETTS

Hitchcock, Edward; American Journal of Science, 1:49:258-265, 1845.

The precipitous ridges and deep vallies of western Massachusetts may be regarded as classic ground on the subject of drift. The force by which the boulders were dispersed and the rocks smoothed and striated, swept over those ridges in an oblique direction; and we are there presented with much striking evidence how independent was this force of existing agencies and of the present configuration of the surface. The leading facts respecting the drift of that region, I have presented in my Final Report on the Geology of Massachusetts. But within the past year I have been invited by Dr. S. Reid, of Richmond in Berkshire County,—himself a zealous naturalist,—to examine a very curious case of transported blocks, found in that town and the adjoining ones; and it is so differ-

ent from any case which I have met with, that I am anxious to bring it to the notice of geologists. For anomalous cases in natural history sometimes reveal to us a general law that governs a large class of phenomena, or rather they lead us to a wider induction than we had made from the ordinary facts.

As one passes a few rods west of Dr. Reid's residence, and about half a mile northeast of Richmond meeting-house, he will see, on either side of the road, numerous angular blocks of stone, of a character quite different from the rock in place, which is limestone. In general the fields are quite free from loose blocks. But on looking southeasterly at this spot, he will see a well marked train of blocks, perhaps thirty or forty rods wide. He may be surprised to see how distinct are the limits of this train. But if he do not follow it further, he will not probably regard it as a peculiarity of much importance: if, however, he turns northwesterly, and follows the train on foot through woods and cleared fields, he will find it pursuing a very direct course, over hill and valley, for about three miles, when he will ascend a ridge, perhaps 600 feet high, in the town of Canaan, New York, where the rock in place corresponds to the blocks of the train; and beyond this ridge, that is to the northwest of it, he will find no more of them. If he now returns to the place where he started, in Richmond, and follows the train southeasterly, he can trace it over the mountain in Stockbridge, through Lee, and up Beartown Mountain, in the northwest part of Tyringham; that is, from its commencement in Canaan, a distance of about fifteen miles. I have not myself followed it so far; but Dr. Reid has, and he knows not how much farther it extends.

The character of the surface along which these blocks are strewn, may be learned from the accompanying map, which exhibits the general features of the topography, and from the section annexed. The heights of the hills, as well as the distances exhibited on this section, were estimated by the eye. But a considerable error in these respects will not affect the deductions drawn in this paper. I have represented the ridge from which the blocks were derived to be about 600 feet above the neighboring vallies. (See ridge A, on the map and the section.) There the train passes over a valley a mile in width, and ascends another broad ridge, (B,) which forms the principal part of the Taconic Mountain at this place, and which I judge to be about 200 feet higher than the ridge in Canaan,—having a valley of some depth near its top. Southeast from this ridge the train crosses a broad valley, some four or five miles wide, lying mostly in Richmond, and ascends another ridge, (C,) lying nearly parallel to the Taconic, called Lenox Mountain, and which may be 500 or 600 feet above the plain. From this it descends into the somewhat level country of Stockbridge and Lee, crosses the Housatonic River, and ascends that broad, irregular pile of mountains called "the Beartown Mountains," (D.)

About half a mile south of the train that has now been described, is another of a similar character, and emanating from the same ridge in Canaan. The blocks in it are less numerous, but its parallelism to the other train is well preserved as far as it has been traced, which, I believe, is not beyond Richmond. Its width is about the same as the other. Between the trains, and in other parts of the town, we meet occasionally with a block of the same kind as the trains: but they are rare; though Dr. Reid thinks it possible that a third train may be found in the south part of the town, where he has observed the blocks to be more numerous.

The rock forming these blocks, I incline to refer to the talcose slate of the Taconic Mountain; and yet it is quite distinct from the usual talcose slate of that range, which forms the west part of Richmond. It is a very hard and tough rock, of a greenish color, and often considerably granular, resembling the older

varieties of graywacke. It frequently contains veins of what appears to be picros-mine, which is quite characteristic, and readily identifies it with the rock in Canaan. In some spots on the parent range, we can see the places where the ragged fragments were torn off by some giant force, and the fracture has yet a considerable degree of freshness,—for this is one of the most enduring of all rocks, being highly magnesian. This ridge, it ought to be remarked, is a part of the Taconic range, which here is separated into several rather low ridges. On the west of the ridge in Canaan, succeed limestone, clay-slate, and the oldest of the Silurian or graywacke rocks.

As we go east from the parent range, the west ridge, as we enter Massachusetts, is the common talcose slate of the Taconic. Then succeeds, in the valley of Richmond, a crystalline limestone; then mica slate in Lenox Mountain; then limestone to the Housatonic; and finally, in Beartown Mountain, quartz rock and gneiss. These rocks are not marked on the map, because they are of no great importance to the point in hand.

I ought to add that the rock of which these blocks consist, is of that intermediate kind which will be referred to different places in the geological scale by different geologists, according to their theoretical views. Nevertheless, it has a character so distinct that even a common observer would not mistake it or confound it with any of the rocks in place over which the blocks are strewn. The opinion that it is serpentine I consider quite untenable.

The blocks composing the trains seem to be confined to the surface. We have a fine opportunity of seeing this where the main train crosses the western railroad. At that spot the road is excavated to a considerable depth into drift, that is rounded. But not one of these blocks is seen mixed with it. They lie only on the surface. Nor could I see any evidence on any of them, that they had been at all subject to attrition. Yet the hills over which they have passed are all smooth-ed and furrowed on their western sides, and by a force acting in the same direction as that which conveyed these angular blocks; but they could not have been concerned in the attrition, otherwise their angles would have been worn off. In short, it is certain that these blocks must have been transported in some very quiet manner to their present situation. Indeed, had they been blasted by human power, and conveyed by men to their places, and arranged carefully in lines, and then suffered to weather for a few centuries, they would appear much as they now do.

I have spoken of these trains as if they pursued an undeviating course. But I must now modify this statement. From their starting point to the middle of Richmond, I could discover no deviation from a right line. But when we come into the broad valley lying between Richmond and Lenox Mountain, the direction changes about 30°. As far as Richmond, the course by the true meridian is E. 34°S. From thence the remainder of the distance, certainly to Lenox Mountain, it is E. 56° S. Possibly there may be another change of a few degrees beyond Lenox Mountain. This change in the course may be seen on the map, where the trains are shown by dotted lines.

The quantity of these blocks, taking the whole length of the trains into account, is immense. In some places they almost cover the ground; as where we begin to ascend the hill to the northwest of Richmond meeting-house. In other places the interval between them is several rods.

Nor is the size of the individual blocks small. They are usually some feet in diameter, and now and then we meet with examples of extraordinary magnitude. At the foot of the hill, northwest of Richmond meeting-house, is the largest I saw. It is 140 feet in circumference, and 12 feet thick. A rod or two distant lies a fragment, which has been detached from the main block, which is 19 feet long, 20 feet broad, and 5-1/2 feet thick. These two blocks, originally one, contain 16,000 cubic feet, and weigh about 1,370 tons. I have seen others as large

nearly; but in several instances they were split into pieces, as if they had fallen from a considerable height into their present position.

Such are the facts. What inferences can we draw from them?

In the first place, these trains of blocks must have been scattered during the latter part of the drift period, and by the same general agency that accumulated the rounded detritus beneath the blocks, and smoothed and furrowed the rocks. The fact that the trains of blocks lie upon the surface above the common drift, proves that they were brought there by an agency more recent than that which accumulated the inferior detritus. But as the force acted in both instances in the same direction, that is, southeasterly, and must have been very different from any other agency that has since acted in that region, we have no good reason for calling in other powers to explain effects so nearly alike.

In the second place, it is impossible to explain this case by any theory of drift, which refers it to the agency of currents of water alone, or of the water and the detritus driven along by its power. The very oblique direction which the train takes across high ridges, would alone refute the idea that water could have done it, even though the whole northern ocean had rushed with the violence of a descending cataract over the spot. But still more absurd does such an hypothesis appear, when we learn that thousands of blocks are strewed over a distance of fifteen miles, not the eighth of a mile in width, and preserving an uniform direction. He who can suppose that a current of water would thus confine such a train of blocks,—some of them of enormous weight,—within such narrow and exact limits, and that too without wearing off the angles of the blocks, must have a very different idea of the dynamics of currents of water from what I have.

In the third place, it is almost equally difficult to explain the dispersion of these blocks by floating iceberg. If the number of blocks had been only one or two, or even not more than fifty, it might be possible that a large iceberg should have dropped them. But what iceberg could have loaded itself with enough of these blocks to have strewed them so thickly for so many miles? And who will believe that successive iceberg, striking against the same ridge in Canaan, should have torn off and borne away successive blocks in precisely the same direction, so as to have lengthened out the train? Besides, although an iceberg would have the power to break off the blocks, where is the agency by which they would be raised upon its back?

Finally, I know of but one or two facts in geology that can furnish us with the slightest clue to the manner in which these trains of blocks were produced. One is, the transportation of blocks of stone in what is called packed ice, upon rivers in high latitudes. These sometimes form lines of boulders along the shore for a considerable distance; as in the river St. Lawrence, described by Mr. Lyell in Vol. 1 of his *Principles of Geology*, (p. 371.) If, therefore, we could suppose a large river passing from the mountain in Canaan across the hills southeasterly, and the climate much colder, it might afford a possible though very improbable explanation of the case. But one has only to look at the region to see, that in its present configuration, this is out of the question, unless a river can flow without a bed, and over ridges 600 or 800 feet high. And as to any essential change of configuration there since the drift period, I think I have proved it absurd in my Final Report.

The second case to which I referred is that of the medial moraines of glaciers; that is, trains of blocks borne along on the back of the middle of the glacier, in consequence of the union of two glaciers, whereby the lateral moraines of the separate glaciers are forced to the surface after the coalescence. One has only to look at such moraines, as represented by Agassiz in his *Etudes sur les Glaciers*, to see that they a good deal resemble the trains of blocks in Richmond; and then, such a mode of transport would show why they are not rounded. But when we come to examine the country with reference to a glacier, we shall find

It about as difficult to imagine the existence of one there as of a river. The country, to the northwest of the ridge in Canaan, from whence the blocks started, descends as far as Hudson River, say 40 or 50 miles; and it is not till we have gone 100 or 200 miles beyond that river, that we have any mountains of much height. And then, if we can imagine a glacier to start from the ridge in Canaan, it must ascend 100 or 200 feet, according to my estimate, in order to go over the next ridge into Richmond; and then again ascend Lenox Mountain and Bear-town Mountain. It is quite as difficult, also, to imagine any cause why the glacier should change its course after passing the first ridge. If it had gone directly down the north and south valley after going over the first ridge, it would not be strange; but it seems to have persisted in going over the next ridges.

A case, which approaches more nearly to the one I have described in Berkshire, is given by Mr. Darwin as occurring in the Falkland Islands, south latitude 52°. "The bottoms of the valleys," says he, "are covered in an extraordinary manner by myriads of great angular fragments of the quartz rock. The whole may be called a 'stream of stones.' The blocks vary in size from that of a man's chest to ten or twenty times as large; and occasionally they altogether exceed such measures. Their edges show no sign of being water-worn, but only a little blunted. The width of these beds varies from a few hundred feet to a mile."

The slope of these streams of stones is about 10°, and they appear to have travelled from the heads of the vallies since the land was raised above the sea. But Mr. Darwin supposes them to have been hurled from the nearest slopes, and then, by powerful earthquakes, to have been leveled into continuous sheets. Did the blocks in Berkshire occupy the bottoms of the vallies, this explanation might perhaps apply to them. But the position of the trains in an oblique direction across the hills and the vallies, renders this theory inapplicable. In short, I find so many difficulties on any supposition which I can make, that I prefer to leave the case unexplained till more analogous facts shall have been observed.

Can glacial theory explain such precise lines of boulders over varying topography?

ESP-004 BOULDER-TRAINS IN BERKSHIRE COUNTY, MASSACHUSETTS

Perry, J. B.; American Naturalist, 4:565-567, 1870.

Mr. J. B. Perry made a communication on "Boulder-trains In Berkshire county, Massachusetts." In Richmond, Berkshire county, Mass., there are six or seven nearly parallel trains of angular boulders, two of them particularly well defined. Attention was called to them years ago by Dr. Reid of Plattsfield. They have been also referred to, and in part described by Sir Charles Lyell, and the late President Hitchcock.

These trains originate partly in a range of hills consisting of chloritic slate, in Canaan, Columbia county, N. Y., but more especially in two other nearly parallel ranges of hills with a meridional trend near the State line in Richmond,

Mass. The latter ranges consist of a greenish slate occasionally interstratified with beds of limestone. For the most part the boulders can be readily traced back to their exact source. Some of the trains may be followed south-easterly for four or five miles; others, passing over the Lenox range of hills, can be traced for ten or fifteen, and one of the larger for some twenty miles. Their direction during the first part of their course is south about 55° east. Somewhat farther on, they change their trend, it being some 35° east of south.

President Hitchcock presuming that there was a submergence of the region, speaks of these lines of boulders as osars; Sir Charles Lyell also supposing a depression, thinks these boulders were transported by coast-ice.

There being no evidence of any considerable depression of this part of the continent during the Glacial Period, even if a submergence would afford an adequate explanation, which it does not, how are we to account for these boulder-trains?

As the vast ice-sheet which spread over the country gradually wasted, the elevations from which these boulders were derived would be at least laid bare. The ice no longer passing directly over the tops of the hills, there is evidence that the mass was parted, moving around the north-eastern and south-western sides of the several peaks. Of course, under these circumstances, the hillsides would be pressed and rubbed, blocks of slate and limestone detached from their places, and borne along upon the surface of the ice-sheet. This being at that time about six hundred feet in thickness, and continuing to thaw, the boulders would be carried forward for some distance, and finally left above the typical drift, as we now find them. As the ice wasted there would be changes in the direction of the moving mass, determined by the character of the underlying surface of solid rock, thus enabling us to account for the variation in the course of the boulder-trains.

Such, in brief, is the explanation suggested for these trains of angular rocks, and for some other similar phenomena in different parts of New England—an explanation in entire consonance with all the known facts connected with the glaciation of the country, and requiring no arbitrary resort to the theory of submergence.

ESP-005 ["ROCK CITIES"]

Tooker, Charles; NEARA Newsletter, 6:13, March 1971.

Library research has revealed that there are at least five quartz conglomerate formations in an approximately 90-to-100 mile strip of New York's Southern Tier. These extend westerly from "Little Rock City" in the town of Genesee, Allegany County, to Rock City Park, five miles southwest of Olean, Cattaraugus County, to the "Thunder Rocks" and "Bear Cave" in Allegany State Park, Cattaraugus County, to Panama Rocks, a few miles west of Jamestown in Chautauqua County.

References to the two "Rock Cities" describe the sites in almost identical words—as resembling an ancient ruined city, with "streets" and "alleys"

between the huge blocks of stone—but formed, in reality, by glacial action, erosion and frost. A work on geology concurs with this.

Correspondence and conversation with one city, two county and two town historians in that area have revealed nothing to indicate any occupation of either the Little Rock City or Rock City Park sites by anyone other than Indians. No Indian legends have been unearthed by us to date.

On May 1, 1971, opening day at this tourist attraction, a visit was made to Panama Rocks. The present owner of the property has not heard anything to indicate human occupation of the site other than by Indians, and the small booklet for sale there concurs with the geological theory.

No indications were seen of anything that might be construed as construction by humans. There are said to be springs on the site which, conceivably, might have supplied water.

The following day, some three hours were devoted to a study of the formations at Rock City Park. Admittedly, this was much too short a time for an in-depth study. Although the site, another tourist attraction, was supposed to be open on weekends at that time, nobody was in evidence to collect entrance fees or to give information—or even sell souvenirs.

Near the entrance, at the highest point on the site, is a large, flat expanse of rock cut by numerous fissures of varying depth, many with ice and snow at the bottom at that time. A small oil derrick was in operation at one point. (Oil is pumped, in very small quantity, at several points on the site. Little Rock City, some 20 miles to the east, also is an oil lease.) The view from this flat expanse is quite impressive.

Here, as at Panama Rocks, a ridge seems to run in a generally north-south direction, with the exposed formations on the east side, although there seemed to be more curvature of the ridge here than at Panama.

Access to the main trail which follows, in most part, the base of the formations, is by means of steel stairs at one end, and by stone steps (called "Indian steps") at the other end. Descent down the latter was treacherous because of ice and snow, and snow necessitated by-passing parts of the trail.

The formations are varied and intriguing. There are huge blocks of stone, some grouped closely together, others spaced at considerable intervals; some only two or three feet in height, others rising to possibly 30 or 40 feet or more. Some of the blocks are remarkably angular at the corners, others are rounded. Two archways, or "natural bridges", were noted. A sign at one point denotes an "Indian fireplace."

An oilman, at work at the pumphouse and other locations, and who claimed to know the area well, stated that the only cave he knew of was what appeared, from outside, to be only a tiny crevice, approached by what possibly could be inferred as two or three crude stone steps. Although it had been reported that there is a cave which will hold 20 or 25 people, it was the oilman's opinion that only two or three might squeeze into the one he showed us. He stated the only sources of water were dry in the summer months.

It seems interesting that at both sites visited, one rock formation of teepee design was encountered, although others could have been missed. Is there a possible significance?

From what was seen, from a purely layman's standpoint, there was no evidence of construction by humans other than noted above. Despite a strong yearning to unearth indications of a "lost civilization", it is difficult to imagine why so many people have seen similarities between this site and "an ancient ruined city".

A similar "rock city" is described by W. Mead Stapler in the NEARA Newsletter, 7:10-15, March 1972, under the title "Baretown—A Pennsylvania Legend."

SECTION ET: TOPOGRAPHIC EVIDENCE

Even nongeologists can appreciate the Mima Mounds, the Carolina Bays, and the great gashes in the continental shelves called submarine canyons. Geologists have marshalled several theories to explain each category of topographic evidence presented below. Generally accepted hypotheses do not exist in most instances. The submarine canyons and guyots are , perhaps, the most significant because they seem to infer great changes in sealevel and geological scenarios radically different from those presently accepted. Carolina Bays and oriented lakes, should they truly be of meteoric origin, would have to be moved into the ETC category, but no consensus seems to exist.

ETB	Carolina Bays, etc. Includes the oriented lakes of Alaska and Siberia.
ETC	Craters and astroblemes. Only the very large and unusual.
ETE	Emergence and submergence. Foundered continental crustal blocks, great changes in topography.
ETM	Mounds and pimpled plains. Mima Mounds, San Diego hillocks, guyots, pingos, and many other grounds of natural (?) mounds.
*ETP	Plans of the earth. Locations of oceans and land masses as related to the evolution of the earth's crust. The tetrahedral theory, and so on.
ETS	Submarine canyons.

•This subsection not represented in Volume E1.

TOPOGRAPHIC EVIDENCE

The human eye is sensitive to order in nature, and the human brain demands explanations of unexpected regularities. The thousands of oriented lakes in Alaska, Siberia, and along the east coast of the United States cry for a good hypothesis. The controversies have been heated and they still persist. Whatever the events were that created these oriented bodies of water the terrestrial consequences must have been great and widespread.

ETB-001 CAROLINA BAYS AND THEIR ORIGIN

Prouty, W. F. ; Geological Society of America, Bulletin, 63:167-224, 1952.

Prouty's study of the Carolina Bays is classic and extensive portions of it are reproduced below—particularly the long summary of geological evidence. Other studies of these Bays are presented in this subsection.

Abstract. The Carolina Bays have a known distribution along the Atlantic Coastal Plain from northeast Florida to southeast New Jersey. Estimates based on actual counts in limited regions indicate a conservative figure of half a million bays in the entire area. Local areas show over 50 per cent coverage by bays.

Statistical studies of orientation show a greater divergence of smaller bays from the mean than of larger bays. Smaller bays also show greater variation in ellipticity than do larger bays. Both facts are most satisfactorily explained by the meteoritic theory of origin. Multiple and "heart-shaped" bays overlap in patterns explained most logically by the impact of tandem meteorites, some likely explosive in nature. The probable mechanics of such phenomena is illustrated. Study of near-coast bays indicate that the bays are younger than the youngest Pleistocene terrace and some of the Coastal Plain drainage and older than at least one of the more recent marine transgressions.

Magnetometer studies of 26 different bays all indicate associated spot highs, with no definite highs observed that are not readily associated with some bay.

Laboratory experiments with projectiles involving simulated Coastal Plain conditions duplicate remarkably the cross-section and rim characteristics of the Carolina Bays and strengthen the meteoritic theory.

Although the meteoritic theory in general is indicated by all critical analyses of the bays, a modified meteoritic theory (air-shock wave) is offered to better explain additional data.

More Important Facts Concerning Carolina Bays. Following are the more obvious facts concerning the Carolina Bays:

1. Bays are geographically restricted to the coastal plain area between southern New Jersey and northeastern Florida, with most of the bays in the two Carolinas and northeastern Georgia.

- (2) Bays are very irregular in their distribution and size.

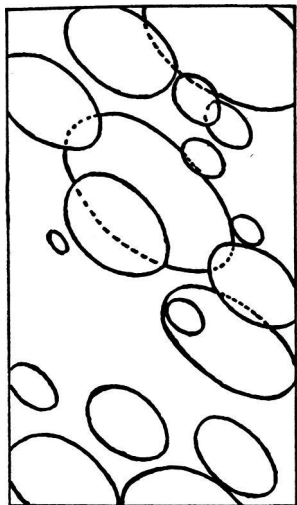
- (3) Bays have no relationship to geological formations, geological age (older or younger terraces), or topography. Some bays are on interstream flatlands, others on valley slopes or older stream terraces, and a few on the older portion of the present flood plain of streams.

4. Toward the northeast and southwest extremities of their occurrence, the bay groups are less numerous and smaller, but as variable in their distribution and size as they are never the center of the area.

5. No bays have been found outside of the sand-covered coastal plain or its erosional remnants, and none should be expected there according to the

air-shock wave meteoritic theory. Large rimmed depressions would not have been formed as readily in the clay soil of the Piedmont as in the sandy Coastal Plain and such rimmed depressions in clay soil would be more readily destroyed by both erosion and sedimentation. On the other hand, buried meteorites would be better preserved in the clay soil than in the previous, sandy soil. The area to the northwest of the known bay country has yielded more meteorites than any other equal area in the United States.

6. An estimate of the probable number of bays, large and small, in the Atlantic Coastal Plain area is about half a million.



Concentration of bays in portion of Bladen County, North Carolina. About 65% of the area is covered by bays, including overlap. Bays smaller than 1900 feet long are not shown.

7. The direction of elongation of the bays is controlled, seemingly, by a force which varies slightly and more or less regularly between the two extremities (northeast-southwest) of the occurrence area.

8. An area of unusually large bays and elliptical lake basins, which includes parts of Cumberland and Bladen counties, North Carolina, is elongated in a direction about parallel to the direction of elongation of the individual bays. This pattern is repeated elsewhere.

9. Bays have sand rims which stand above the general level of the land and are best developed generally at the southeast end of the bay, especially the eastern portion of the southeastern end. The poorest development, as a rule, is along the west and northwest sides, although even there some bays have fairly well developed rims.

10. Rimmed depressions of similar ellipticity can readily be formed by the air-shock waves created by a rifle bullet shot at an angle into a light powder, such as plaster of paris powder, resting on plastic clay. The rimmed shock-wave depression made in the powder is many times the diameter of the hole made in the plastic clay by the projectile. The ellipticity of the depression depends upon the angle of penetration.

11. The larger bays generally have larger rims, but local conditions modify the size. Rims are better developed where a bay is located in a high and dry sandy area rather than in a low and wet sandy area.

12. The deepest part of the bay is usually toward the southeast end and a little west of the axial line.

13. The similarity of development and the condition of preservation of bays in all parts of the "bay country" seems to indicate that they are all of about the same age.

14. Similarity of rock character, climatic conditions, groundwater, and topography seem to be as favorable for the formation of bays in bordering areas as in the areas of known occurrence.

15. Elliptical sand-rimmed bays are not being formed anywhere in the world at the present time as far as known.

16. There are no well developed bays or beach ridges for a distance of 7 miles northwest from Myrtle Beach, South Carolina. This area was either covered by the ocean at the time of the formation of the bays, or else the ocean returned to cover and destroy the bays formed in the area. In many low, near-coast areas, the bays have apparently been considerably effaced by marine or lagoonal sedimentation and erosion.

17. Most bays are associated with other bays of slightly different age. These associated bays frequently overlap. The overlapping younger bay completely obliterates that portion of the older bay overlapped. Occasionally a small bay is contained wholly within the area of the larger bay. The rim of the smaller bay usually rises above the level of the swamp or lake of the larger bay. Some unusually elongated or unusually broad bays are found to have been formed by a number of associated and overlapping bays. The overlap direction of twin or multiple bays in North Carolina is generally more to the northwest than to the west, thus creating some unusually elongated multiple bays in that area. Toward the southwest in the South Carolina-Georgia area, such overlap direction is frequently more toward the west, so that the multiple bays in that area are broadened rather than lengthened. Some oval or heart-shaped bays appear to derive their shape from two or more overlapping bays which have a slight convergence of their long axial directions toward the southeast; in such cases, the bay unit on the west has the smaller azimuth (counter-clockwise rotation) of orientation.

18. Many bays have more than one rim usually along the southeast and east sides. In some cases where rims are broad and high, these successive rims are the result of multiple bay formation. In these bays, each newer overlapping bay is formed slightly more to the west or, in other cases, to the northwest or north of its predecessor. In many cases of overlap, the only portion of the older bay not concealed by the overlap is a small crescent portion of one side. Where the inner rims are comparatively small and appear more or less symmetrically placed in respect to the plane of symmetry of the bay and with development limited to the southeastern two thirds of the bay, the origin of the rims may be associated with the forces forming the larger and outer rims.

19. In a number of cases, a later-formed bay has cut across earlier-formed outer and inner rims of a single bay, thus indicating that the two types of rims were closely associated in time of formation, if the meteoritic theory of origin is assumed.

20. In soluble rock areas, many of the bays are being modified by solution and some can now be classified as sinks—"bay sinks." Sand rims are being lowered in some regions by groundwater moving from the bay underneath the rim to a stream which is "heading up" toward the bay and at a lower level than the water table in the bay.

21. A very small proportion of bays drained by streams are drained from the southeast end, but more often from the southwest, west, northwest, or east sides, indicating drainage by normal headward erosion of tributary streams.

22. Many bays have been partially filled by stream deltas, more often entering from the northwest, north, or northeast sides.

23. Many bays have been partially filled by windblown sand from the southwest, west, and northwest. In such cases the sand is usually finer-textured than that of the average rim.

24. Sand dune areas in many cases extend northeastwardly from the east and northeast sides of the bay.

25. Samples taken from one medium-sized bay just beneath the thick peat deposits show a gradation from medium-coarse sand near the sides of the bay to silt in the central portion of the bay.

26. Near Myrtle Beach, South Carolina, the inland waterway cuts through the north-central portion of two small contiguous bays to a depth of about 25 feet. The two continuous shell beds found elsewhere along the canal are absent in the central portion of the section through each of these two bays. These shell beds must have been removed by either chemical or physical means. Nowhere else along the canal beneath the peat deposits, former swamp areas but not bays, have the shell beds been removed.

27. In Bladen and bordering counties, North Carolina, where large bays and bay lakes are numerous, it is not unusual to find large areas with more than 50 per cent of the surface covered by bays, and in much of this area the bays will also have an overlap of 10-25 per cent or more.

28. Practically every bay, large or small, surveyed by magnetometer has a well defined spot magnetic high or highs associated with it. If there is a single spot high, it usually occupies a position a little east of south from the southeast end of the bay at a distance about that of the short axis of the rim from the southeast end (the "Prouty Rule," so-called by Douglas Johnson, 1942). If there are two or more associated spot magnetic highs, the distance of each from the southeast end of the bay is considerably less than in the case of a single spot high. There is considerable variation in the direction of the spot highs from the bays as well as in the size of the spot highs in relation to the size of the associated bay. This variation seems logical from the variable conditions encountered.

29. In some parts of the coastal plain area, linear magnetic highs are present. These usually trend in a northeast-southwest direction and tend to swell and diminish along the strike, making it difficult to entirely eliminate their effects from the spot high magnetic readings.

30. Many of the bays have a slightly flattened elliptical border on the southwest side. In some cases this may be accounted for by eastward- or northeastward-drifting sand; in other cases, the reason is not clear but may have some connection with the development of the deeper part of the bay, which is toward the southeast end and to the west of the median line. Also, in multiple bays, the later-formed bay usually is responsible for the northwest portion of the bay rim and this later formed unit of the multiple bay has a slight counter clockwise orientation from that of the earlier formed unit of the bay responsible for the southern portion of the west rim. These conditions result in a somewhat flattened southwest rim.

31. The rim sand of bays is in general a little coarser than the average sand

of the area. This is to be expected according to almost every theory, including the meteoritic air-shock wave theory. The coarseness is emphasized by the down wash of the finer material or by the very important action of ants which live on the dry sand rims. In building their nests, the fine grains are left below and the coarse ones are brought to the surface; also wind tends to move the fine sand grains from the rim. If air-shock waves are responsible for the rim formation, one would expect the fine sand particles to be carried farther from the depression than the coarse particles.

32. The sand in the rim shows little, if any, stratification. The formations beneath the rim appear to be undisturbed. There are no known deep sections across the bays at the critical points (deepest area in bay). A rumor of the presence of a "pipe" of disturbed ground beneath bays has not so far been verified.

33. Metallic iron, fragments of basement rock, or fused glass have not been found in association with any of the Carolina Bays. They should not be expected in view of the porous soil and climatic conditions.

34. All bays were formed on the superficially sandy Pleistocene terraces of the coastal plain and are younger than any of the well developed beach ridges with which they are associated, as shown by the fact that they cut across these ridges. An exception to this is found in some bays near the coast, where temporary marine flooding has both largely destroyed the sand rims and built faint beach ridges and swales across the bays.

35. In a few places there is direct evidence that the sea has encroached upon some of these bays since their formation and has again withdrawn, as in Blythe Bay, Wilmington, North Carolina, where peat deposits in the bay have been covered by sediments of probable marine origin. Later elevation and stream erosion has cut through the sediments and into the peat.

36. A few are known to have lake bottom springs. Most of these springs are near the southeast end of the bay.

37. Bays are generally largely filled with peat which apparently has a maximum thickness of from 15 to 30 feet. The peat filling reaches an elevation a little below the general level of the surrounding area. This elevation is governed by the height of the water table.

38. Bottom samples from the deeper part of some of the bays in Bladen County, North Carolina, taken from beneath the peat deposits, show a thickness of several feet of light-colored silt which, according to B. W. Wells (personal communication) is of wind blown character. The deposition of silt over the coarse bottom sand shows that the bays were formed suddenly and were soon filled with water, then followed sedimentation from a wind swept barren area. It is apparent that a slow sinking depression such as postulated by either solution or artesian springs could not yield the type of profile shown in these bays. According to Wells, the slow sinking postulated by either the solution or the artesian spring theory would yield deposits containing shallow-water or marsh-plant pollen. Instead of this there is a silt deposit without marsh-plant pollen made in deep water. The silt grades at top into aquatic peat containing pollen from water lillies and from trees of boreal or cold climate type.

Distribution, Coverage, Number, and Grouping of Carolina Bays. The Carolina Bays are entirely confined in their occurrence to the Atlantic Coastal Plain and a few coastal plain outliers. The large percentage of these rimmed, elliptical depressions are found in South Carolina and southeastern North Carolina. The bays also occur in rather large numbers for some distance to the west of the Savannah River in Georgia. Scattered bays also occur in the south and north central parts of the Georgia Coastal Plain in groups and clusters, as they do in the north central part of the Coastal Plain of North Carolina. A

very few scattered bays are to be found even in extreme northeastern Florida and in the Chesapeake Bay Region of Virginia and Maryland, and three or four questionable bays exist in New Jersey.

Concentration of large bays occurs in some localities as does the concentration of small bays in other localities, but in general there is a fairly uniform mingling of sizes in the distribution. In some parts of the bay area, a number of overlapping bays occur in a northwest-southeast line, giving elongated "multiple bays." In other parts of the area, several bays overlap, making broad, more or less pear-shaped or heart-shaped "multiple bays." Roughly speaking, the large bays occur in greater proportion in two large districts, one in the southeastern North Carolina-northeastern South Carolina district and the other in the southwestern South Carolina-northeastern Georgia district. The North Carolina district includes the large Lake Waccamaw bay which has a length of over 6 miles, a sand rim at the southeast end about 23 feet above the lake level, and a width of over 2000 feet. At several localities in the Carolinas, small bays are found within a few hundred yards of the inner edge of the coastal plain. In a few localities in Georgia, "ghost" or remnant bays are found on coastal plain outliers a little distance into the Piedmont from the unbroken coastal plain line. These outliers were formerly part of the Coastal Plain before streams removed much of the sand cover from the underlying Piedmont rocks.

Some bays were without doubt formed in the lowlands, in many cases river bottoms, as well as in the interstream areas and valley slopes. Skeleton bays can be seen in a few places in the floodplain of the Cape Fear River and partially destroyed bays can be seen along the present river banks. Some bays project across waterways or are partly concealed by river swamps. There are no bays to be seen in the more recently formed portions of the Coastal Plain and for 7 miles inland from the coast town of Myrtle Beach, South Carolina. Going inland and north toward Conway, South Carolina, the first bays to be seen show signs of having been partially destroyed by wave action. It is logical to conclude that the bays were either formed in shallow water along the sea coast of that time and were partially destroyed before the ocean retreated to its present position, or that the ocean raised after the formation of the bays and migrated back to the position of the partially destroyed bays before retreating to its present position. Partial destruction of bay rims is to be seen in a number of places along the coastal areas and in places several miles back from the present shore. Study of plant remains in the sediments of the present coastal swamps and beach ridges by Professor Wells (personal communication) confirms the theory that there has been a relatively recent sea advance and retreat along a considerable portion of the coast line of the Carolinas. In the Wilmington, North Carolina, area, as pointed out also by Wells, peat deposits in Blythe Bay which have been covered by several feet of marine sediments are now exposed by stream erosion. This seems to show a marine invasion and retreat some time after the formation of the peat in the bay.

As far as known the Carolina Bays were formed under both geographical and time limitations, later than the formation of most of the Pamlico Terrace.

The area of distribution of the bays is about 83,000 square miles. Of this area, perhaps 43,000 square miles have very few or no bays. The bays cover, including overlap, roughly about 10 per cent of the surface. Where bays are large and thickly distributed, they may cover more than 50 per cent of the surface. Two large areas in Bladen County, North Carolina, were measured. In one of these, 7 miles long by 4 miles wide, the area covered by bays was found to be a little over 50 per cent. Another section of Bladen County, 5 miles by 4 miles, had a bay area of 67-1/2 per cent. In places, 20 bays to the square mile, each longer than 500 feet, have been counted. Some of the large bays

cover several square miles. These, in some cases, may be made up of several overlapping bays. Many bays are concealed in heavily wooded, swampy, or river-bottom lands.

A conservative estimate of 3.5 bays to the square mile, each longer than 500 feet, gives an estimate of 140,000 bays of moderate and large size. It is almost impossible to estimate the number of small bays. One might be justified in roughly guessing that the total number of bays, large and small, is about half a million.

ETB-002 ORIENTED LAKES OF NORTHERN ALASKA

Black, Robert F., and Barksdale, William L. ; Journal of Geology, 57:105-118, 1949.

The Alaskan oriented lakes have some features in common with the Carolina Bays, which may be of meteoric origin. Even if the Alaskan lakes have a more mundane origin, their very regularity is curious: and, as the authors admit, their origin(s) are not yet clear.

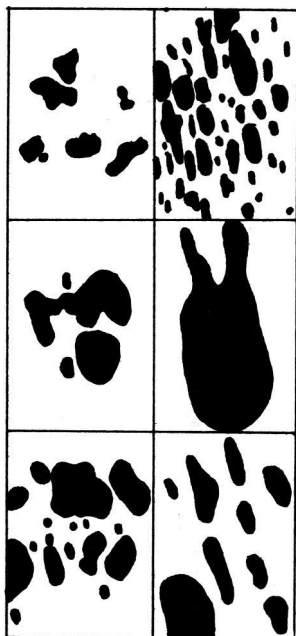
Abstract. The oriented lakes of northern Alaska occur in an area of more than 25,000 square miles in the Arctic Coastal Plain Province. The topography, drainage, vegetation, climate, geology, and permafrost of the area are briefly described. The average range of orientation of the lakes is 12° from N. 9° W. to N. 21° W. In any locality the deviation from the average is commonly less than 3° and rarely over 5°. The lakes range in size from small ponds, a few tens of feet in length, to large lakes more than 9 miles long and 3 miles wide. The shapes may be described as elliptical, cigar-shaped, rectangular, ovoid, triangular, irregular, or compound. One group of lakes has a shallow shelf or underwater bench surrounding a deeper central portion. The rest are shallow throughout, and the underwater profile is commonly concave. The major outline of the lakes is smoothly curved, but in detail it is cusped or jagged. No lacustrine beach ridges were recognized. Former lake basins, now drained, and extensions of the present lakes are evidenced by shore features, lacustrine deposits, the character of polygonal ground, and vegetation. The effect of wind, vegetation, and permafrost are briefly described. The lakes are compared with the Carolina Bays and with rectangular lakes in eastern U. S. S. R. Many of the lakes are believed to be the result of thawing of permafrost; others may be produced by the segmentation of uplifted lagoons. The origin of some is not known.

General Statement. The oriented lakes of northern Alaska occur in a remote and sparsely inhabited area of more than 25,000 square miles adjacent to the Arctic Ocean. The origin of the thousands of lakes has aroused the curiosity of most men traveling on the Arctic slope; however, few systematic data have been collected regarding their origin or their remarkable parallelism. The areal extent and orientation of the lakes probably has been recognized only since observations could be made by air or from aerial photographs.

Method of Investigation. The oriented lakes first came to the attention of the senior author, R. F. Black, during the summer of 1945. In the summer of 1946, in connection with the permafrost investigations of the United States Geological Survey, W. L. Barksdale visited numerous lakes along the Meade River and in the vicinity of Barrow. R. F. Black, assisted by Donald R. Loftus, visited many lakes along the Arctic coast southwest and southeast of Barrow, in

the vicinity of Barrow, and in the Cape Simpson area. Several trips were made by air from Barrow south and east over the lake country. Trimetrogon photographs, taken in 1942, 1943, and 1945 of most of northern Alaska, were used as a base for delimiting the areal extent of the lakes and for providing data in places not visited. Planimetric maps, on the scale of 1/48,000, made by the Geological Survey from these aerial photographs, provide coverage for most of the entire area.

The authors have not had an opportunity to study in detail the many aspects of the oriented lakes; however, in the light of the increasing interest in Alaska it seems desirable to present the available information at this time. The Geological Survey anticipates further studies of the oriented lakes and associated permafrost phenomena.



Representative outlines of some Alaskan oriented lakes, showing size, shape, and orientation. Rectangles are about 4 miles wide. North is straight up.

Topography. The area occupied by the oriented lakes of northern Alaska covers almost completely the physiographic province known as the Arctic Coastal Plain. The Coastal Plain is the northern-most physiographic province in Alaska and is bordered on the south by the Arctic Plateaus Province. The boundary between the Coastal Plain and the Plateaus has been arbitrarily chosen on the basis of topography and of distribution of Quaternary sediments. In general, that boundary is between 400 and 600 feet in altitude, although Leffingwell reports that on the Okpilak River, 40 miles from the coast, the boundary is about 1,200 feet. East of the Sadlerochit River (outside the area of the oriented lakes and not shown on fig. 1) The Coastal Plain widens abruptly to about 50 miles and narrows where the British Mountains approach the ocean at the international boundary line.

In some places the Coastal Plain grades imperceptibly into the northern front of the Arctic Plateaus. In the Canning River area, the northern front of the Arctic Plateaus rises with a slope of 15°-20° from the flat Coastal Plain and may be as much as 300 feet higher.

To the north the profile of the Coastal Plain is broken only slightly by the Arctic Ocean. In many places the plain is only 1-10 feet above the sea. The average height of coastal bluffs is only 15 feet, and the highest rise 25-50 feet above sea level. The shoreline is characterized by many offshore bars of silt and sand, mud flats, and spits. Lagoons, in places as much as 5 miles wide and many tens of miles long, are generally less than 10 feet deep.

Except for minor features, the Coastal Plain extends with monotonous flatness from horizon to horizon. Broad low ridges and valleys have a very low relief of about 30 feet. Locally steeper slopes of former wave-cut benches or wave-built benches or beaches occur. Small earth and ice mounds, commonly 1-4 feet high, occur over most of the plain. Shallow troughs, commonly less than 2 feet deep and in many places underlain by vertical wedges of ice, form a network (polygonal ground) over most of the surface.

Drainage. All runoff is on the surface, as permafrost underlies the entire Coastal Plain at a depth of a few inches. All but the largest rivers, such as the Colville River, freeze solidly to permafrost every winter. It is estimated that possibly 50-75 per cent of the Coastal Plain is covered with lakes and marshy ponds. Many are without external drainage except in spring, when high waters overflow their banks. Certain localities are partially dissected, and some lakes are draining through recent gullies.

Only one large river, the Inaru, lies entirely within the limits of the Arctic Coastal Plain Province. However, most rivers that head in the Arctic Plateaus Province or on the north flanks of the Brooks Range cross the Coastal Plain on their way to the Arctic Ocean.

Vegetation. The entire Coastal Plain is a treeless, prairie-like tundra region characteristic of the arctic and subarctic zones. It is covered with a thick mat of vegetation composed of a mixture of lichens, mosses, grasses, sedges, shrubs, and other plants. Small prostrate shrubs are rare along the coast but are more abundant inland. Willows are particularly common along the protected banks of the larger streams, though they rarely grow as high as 10 feet. Evergreen or large deciduous trees are absent.

Climate. The climate on the Arctic slope is cloudy, cold, arid, and windy. The only weather station on the northern Coastal Plain of Alaska is at Barrow, but data collected there since 1912 by the United States Weather Bureau are probably applicable to the entire coastal area. Monthly and annual climatic data are given in table 1. [deleted]

The annual mean temperature at Barrow is 10°F.; the annual mean maximum temperature is 16°F.; and the annual mean minimum temperature is 4°F. The monthly mean maximum and mean minimum temperatures are shown in

figure 2. The absolute maximum temperature is 78 F. and the absolute minimum temperature is -56°F. The monthly and annual number of days with freezing temperatures are shown in table 1.

During a period of 27-30 years the most frequent wind direction was northeast during every month except July, when it was southwest. The prevailing direction and relative velocity of the wind at Barrow are shown in figure 3. The average monthly and annual wind velocities are shown in table 1.

Geology. The Arctic Coastal Plain is underlain by several thousand feet of relatively impervious sandstones, shales, and some interbedded conglomerates, coals, limestones, and bentonites of Upper Cretaceous and early Tertiary age. These rocks are essentially flat-lying, although gentle folding has produced large low domes and anticlines and broad, shallow basins and synclines. Dips are commonly less than 5°.

The Upper Cretaceous and early Tertiary rocks are mantled uniformly throughout much of the Coastal Plain by unconsolidated clays, silts, sand, gravel, and peat, as much as 150 feet thick, of late Tertiary-Quaternary age. The unconsolidated sediments are of interfingering marine and fluvial origin, and different deposits vary widely in areal distribution, thickness, and composition. The detailed geologic history and relations of these deposits are known for only a few areas.

Permafrost. All surficial deposits and the bedrock to a depth of several hundred feet under the Arctic slope are permanently frozen. The surficial deposits, in particular, contain large quantities of ice in the form of nearly vertical ice wedges, horizontal ice sheets, irregular ice masses, and small grains, crystal, stringers, irregular particles, and films of ice as a cement. Shallow thawed zones probably occur under the larger streams and below some of the deeper lakes. Summer thaw penetrates from 6 inches to a maximum of about 30 inches. The average summer thaw is about 8-20 inches.

Distribution. The oriented lakes occupy almost completely the Arctic Coastal Plain Province of northern Alaska and, as far as is now known, are limited to that province. The northern limit of the lakes is the Arctic Ocean. The southern limit coincides approximately with the boundary between the Coastal Plain and the Plateaus Province, from the Arctic Ocean near Cape Beaufort, about 450 miles eastward, to the Arctic Ocean near the Kalakturuk River. Although the Arctic Coastal Plain Province continues east of the Sadlerochit River to the international boundary, the lakes in that area are apparently not oriented. The maximum width of the oriented-lake area, from Barrow southward, is more than 100 miles. The average width is between 50 and 80 miles.

Oriented lakes occur chiefly in lowland areas and less commonly on the sides or tops of low ridges. Many are in basins cut directly into broad, featureless plains. Others are present in lowland areas along coasts, on tops of high bluffs, and less commonly in river floodplains.

Concentration. The oriented lakes are concentrated in elongated belts or zones, which apparently represent former stages in the uplift of the Coastal Plain. It is estimated that locally the lakes or drained lake basins comprise from less than 25 per cent to as much as 90 per cent of the surface of the land, although in most places the lakes probably comprise between 50 and 75 per cent of the surface. Most of the oriented lakes are concentrated in a large area north of latitude 70° and between the Kuk River on the west and the Itkillik River on the east. The number of oriented lakes is markedly less along the southern boundary of the area, and particularly so in two areas of slightly higher relief and coarser-grained surficial deposits, one of which lies between the Itkillik and Kuparuk rivers and the other between the Sagavanirktok and Shaviovik rivers, where only remnants of former oriented lakes remain. In certain

areas adjacent to the coast, along many of the larger rivers, and wherever slopes are moderate, gullies have intersected and largely drained the oriented lakes without, however, completely destroying the lake basins themselves.

Orientation. The remarkable parallelism exhibited by the thousands of elongated lakes in the Arctic Coastal Plain Province in northern Alaska is a rare phenomenon and, so far as is known, is duplicated in such a marked degree only by the Carolina "Bays" of the Atlantic Coastal Plain Province of the United States. The uniformity of alignment of the lakes is so perfect in many parts of the Arctic Coastal Plain that their orientation has been used as an aid in air navigation.

In order to determine accurately the regional orientation of the lakes, the long axes of five to twenty lakes in a particular locality were determined by bisecting the outlines of the lakes as shown on Geological Survey planimetric maps; the trend of the axes was measured; and the average trend determined arithmetically. The number of lakes measured was increased as the variability of orientation increased. Of the well-developed lakes oriented in a northerly direction, the total range in orientation is only 30° —from north to $N. 30^{\circ}W.$ The average range for seventeen localities, as shown by the arrows on figure 2, is only 12° —from $N. 9^{\circ}W.$ to $N. 21^{\circ}W.$ In any one locality the deviation from the average is commonly less than 3° and rarely over 5° . The lakes in the southeastern part of the Coastal Plain in the vicinity of the Colville River at latitude $70^{\circ}00'$ trend more nearly west than do the lakes in the rest of the Coastal Plain. Most lakes in the central portion of the Coastal Plain north of latitude $70^{\circ}00'$ and between the Kuk River on the west and the Ikpiuk River on the east trend $N. 13^{\circ}W.$ to $N. 15^{\circ}W.$

Not all lakes on the Coastal Plain are oriented, nor are all oriented lakes aligned in the same direction. The north-northwest trend is uniformly developed throughout the region. An easterly trend is shown by a few lakes in scattered localities but is nowhere so pronounced as is the north-northwest trend. Rarely, individual lakes along the coast or in the floodplains of some of the major rivers are oriented in other directions, but no other pronounced trends were noted.

Lakes which are not oriented occur in the area along the southern limits of the Coastal Plain, in the areas of higher topographic relief between the Itkillik and Kuparuk rivers and the Sagavanirktok and Kadleroshilik rivers, in certain relatively high sections along major streams, and on the floodplains of many streams.

The oriented lakes in some places form groups or chains that are aligned along the axis or at an angle to the axis of individual lakes composing the chain.

Character of the Oriented Lakes. **Size.**—The oriented lakes range in size from small ponds a few tens of feet in length to large lakes more than 9 miles long and 3 miles wide. Lakes of all sizes occur in any locality, although large lakes are more numerous in a broad zone adjacent to the coast from Barrow eastward and as far south as latitude $70^{\circ}30'$. Many of these lakes are 4-6 miles long and 1/2-1 mile wide. Lakes are conspicuously less numerous and smaller east of the Itkillik River than west of that river, and they are, in general, less numerous and smaller toward the southern boundary of the Coastal Plain.

Lake Teshekpuk, about 80 miles southeast of Barrow, is an unusually large and irregular lake more than 21 miles wide and 29 miles long.

Shape.—The shapes of the lakes of the Coastal Plain may be described as elliptical, cigar-shaped, rectangular, ovoid or egg-shaped, triangular, irregular, or compound, having any combination of these shapes. All the lakes are somewhat irregular, and few are so smooth or so perfectly formed as to fit clearly into any one type. Any one or more types may predominate in a particular locality, although in most areas all types are at least represented.

Ratio of length to width.—The ratio of length to width is as variable as the shapes of the lakes; it ranges from almost 1:1 to more than 5:1. Many well-developed elongate lakes in the central portion of the Coastal Plain, north of latitude 70°00' and between the Kuk and Ikpiuk rivers, have ratios of 2:1 to 3:1; and many lakes in a zone 20-50 miles wide along the coast from the Kuk River to Harrison Bay, 105 miles southeast of Barrow, have ratios of from 3:1 to 4:1. The ratio is considerably smaller in the far western part of the Coastal Plain and approaches 1:1 along the south border and in the plain east of the Itkillik River.

Depth.—The oriented lakes range in maximum depth from about 2 to 20 feet or more. Although the depths of the existing deeper lakes have not been determined, measurements of drained lake basins formerly occupied by oriented lakes show that some were at least 60 feet deep.

As a preliminary and tentative classification based on depth and underwater profile, the lakes may be divided into two groups. One group consists of those lakes which have a shelf or shallow underwater bench surrounding a deeper central portion. The other consists of those lakes which are relatively shallow throughout and whose underwater profile is uniformly concave. The two types are usually distinct, although gradational forms exist and absolute classification cannot be adhered to for all lakes. Those few lakes for which underwater data are available and whose maximum depth is less than 6 feet belong clearly in the second group, and those exceeding 6 feet in maximum depth belong in the first. In general, the shallow lakes with uniform concave profiles are most abundant in the northern part of the Coastal Plain, and the deeper lakes with shallow shelves are more abundant in the southern part.

Shore features.—As seen from the air, the major outline of many oriented lakes is smoothly curved, but in detail all shorelines are cusped, uneven, or jagged. The degree of unevenness varies from one part of a lake to another and from lake to lake throughout the Coastal Plain. In general, the western shorelines of the oriented lakes are the most uneven, and the eastern shorelines slightly less so. Although the northern and southern shorelines are less smoothly curved in major outline than are the western and eastern, they are generally not so rough or jagged in detail. Relatively smooth, curved shorelines are shown in plate 2, A, and cusped or jagged types in plate 2, B.

From the ground, the unevenness can be clearly seen in some lakes but it is less pronounced in others.

The height of the shore may be different from one part of a lake to another and from lake to lake throughout the Coastal Plain. Generally, the highest shores are on lakes in the southern part of the Coastal Plain. Low wave-cut bluffs range from less than 1 foot to 20 feet above water level and are composed of sand or silt, clay, and organic material. In other parts of the same lake the shoreline grades into marshes. Beaches border some shorelines at low water or when winds are blowing the water away from shore. As far as is known, no lacustrine beach ridges occur around any lake on the Coastal Plain, but all lakes are incised below the general level of the tundra.

Former Lake Basins. Drained lake basins and former extensions of the present lakes are indicated by wave-cut and wave-built shores, beaches, lacustrine deposits, character of polygonal ground, and character and distribution of vegetation. The evidence shows conclusively that most of the present lakes were much larger than they are today and that many formerly oriented lakes are now completely drained. The abandoned lake basins are clearly visible from the air and in aerial photographs and less clearly from the ground. Polygonal ground, commonly in a rectangular pattern emphasized by vegetation, parallels and outlines the old shorelines.

The degree of dissection of the old lake basins varies widely. Some are occupied almost entirely by lakes; others are completely drained and almost obliterated by surface erosion. The former lakes were parallel to one another and commonly overlapped. The present lake may occupy all, or nearly all, the lake basin; it may be much smaller but similar in shape and orientation; it may be smaller and have no resemblance to the original basin; or it may consist of several ponds, oriented or unoriented, occupying parts of the original basin.

Effect of Wind, Vegetation, and Permafrost on the Lakes. All the oriented lakes are being modified by wind, vegetation, and permafrost.

The dominant east-northeast and west-southwest wind directions are demonstrated by weather records at Barrow, by alignment of dune sands and blow-outs along the west and east sides of rivers, and by wave erosion along the west and east sides of the lakes.

The shallow lakes, those less than about 6 feet in depth, are directly enclosed by permafrost. Under the deeper lakes thawed zones extend possibly to a few yards below lake bottom, but around the shore permafrost is only a few inches deep. In spite of the short cloudy summers, the waters of many lakes warm up to 40° or 50°F., and thawing accompanied by wave action on the frozen sands, silts, and mucks in the banks of the lakes produces very rapid erosion of the shores during storms. Caving, slumping, and erosion of as much as several tens of feet of the shores of some lakes may occur in a few weeks during the summer months. This process results in the cusped, uneven, or jagged shoreline so common around the lakes and along the coast and permits one lake to intersect or capture other lakes.

In contrast to the enlarging effects of thawing of permafrost and subsequent wave erosion, vegetation (commonly Colpodium fulvum) in shallow parts of the lakes tends to reduce and finally to eliminate wave erosion, to fill in parts of the lake with plant material, to insulate and protect permafrost from thawing and caving, and to aid in the building-up of permafrost.

These processes go on simultaneously in different parts of a lake or at different times in the same part of a lake. Either destructive or constructive processes may predominate at any one time or period, and apparently they follow cycles connected with such variable factors as temperature, rainfall, cloudiness, wind direction and velocity, and cosmic conditions.

The present tendency is toward destruction of the northerly orientation of the lakes and toward an easterly orientation in those lakes with sufficient "reach" for wave action to be effective. Many lakes are enlarging rapidly as permafrost thaws and waves remove the unconsolidated material forming their shores. These lakes are also becoming shallower, and those too shallow or too small for wave action to be effective are being filled by vegetation. Other lakes are being destroyed by dissection accompanying thawing of permafrost.

In general, the weather data and field observations indicate that the cold reserve of permafrost on the Coastal Plain of northern Alaska is building up by the removal of heat from the ground.

Comparison of the Oriented Lakes of Northern Alaska with the Carolina Bays and Other Oriented Lakes. As far as is known, this paper contains the first description of a group of oriented lakes which compare in number and in extent of orientation with the Carolina Bays of the eastern United States. Up to the present time the Carolina Bays have been unique, for nowhere else had such a large area containing such well-oriented lakes been known.

The Carolina Bays have been discussed at great length by Douglas Johnson, and it is from his book that data are derived for the comparison with the oriented lakes in table 2. [See p. 2211

Obruchev reported that rectangular lakes oriented in a rectangular pattern occur on the Recent Arctic Coastal Plain to the southwest of the Iamskaia beach of the Okhotsk Sea, in the valley of the Penzhina River near the village of Penzhino, and in the valley of the Anadyr River. These lakes are reported to vary in diameter from several hundred meters to as much as 5 km. Those on the plain surrounding the Okhotsk Sea are parallel to the coast. Obruchev believes that the origin of the lakes in the valley of the Penzhina and Andyr rivers is connected with the origin of the polygonal ground which occurs in the area, but he does not explain further. He believes that many of the lakes less than 2 meters in depth are the result of the thawing of permafrost. Some lakes deeper than 2 meters are fed by fresh-water springs and others by mineralized waters from taliks, or thawed zones within the permafrost. Seasonal and biennial mounds are reported to rise from the bottoms and from the shores of some of the lakes. It is not known how well the lakes are oriented or how large an area they cover. They are presumed to be Quaternary in age.

Johnson briefly discusses oriented lakes of undetermined origin in Florida, Georgia, and Texas and comes to the conclusion that they are similar to, but not identical with, the Carolina Bays.

Theories of Origin of the Oriented Lakes. The data on the oriented lakes of northern Alaska are too few to permit any definite analogy with the Carolina Bays or with other groups of oriented lakes. However, the Carolina Bays and the oriented lakes of northern Alaska are so strikingly similar that it is believed that the conditions under which they were formed and the physical processes operating to produce them must have been, at least in part, similar. An analogy may be drawn also between the oriented lakes of northern Alaska and the rectangular lakes of eastern U. S. S. R., although data for this comparison are much less satisfactory.

Many conflicting and widely divergent hypotheses are advanced by various authors to explain the many perplexing problems involved in the origin of the Carolina Bays. Johnson gives complete references to the numerous papers and discusses all hypotheses. Three of the most outstanding hypotheses are: (1) meteoritic origin, by F. A. Melton, William Schriever, et al.; (2) segmented lagoons and crescent-shaped keys, by C. Wythe Cooke; (3) artesian-solution-lacustrine-aeolian hypothesis, by Douglas Johnson.

Of these, the meteoritic hypothesis caused the greatest excitement in the scientific world, but, with certain exceptions, it is not now so widely believed as before. The fact that the oriented lakes are limited only to the Arctic Coastal Plain and almost completely cover that plain, that magnetometer and geophysical surveys do not indicate any deposits of meteorites, and that the shapes of the lakes and absence of "rims" do not conform to such a theory points to the conclusion that the meteoritic hypothesis does not explain the origin of the oriented lakes of northern Alaska.

With some modifications, Obruchev's "cave-in" hypothesis, Cooke's segmented-lagoon hypothesis, and Johnson's complex hypothesis probably will explain some of the problems connected with the origin of the oriented lakes of northern Alaska.

The writers believe that many lakes of northern Alaska, some oriented and others unoriented, are the result of thawing of perennially frozen ground and are true "cave-in" lakes. These lakes may or may not occupy parts of the basins of oriented lakes now drained, and they are possibly of more than one generation. "Caving" in itself, however, cannot produce regional orientation.

TABLE 2

Comparison of the Oriented Lakes of Northern Alaska with the Carolina Bays

	Oriented Lakes of Northern Alaska	Carolina Bays
Distribution	Total area of more than 25,000 sq. mi.; limited to the Arctic Coastal Plain	Total area of at least 25,000 sq. mi.; limited to the Atlantic Coastal Plain
Abundance	Probably tens of thousands of lakes or lake basins	Probably tens of thousands of bays and possibly hundreds of thousands
Orientation	Most trend from N. 9°W. to N. 21°W.; average trend is N. 12°W.	Majority trend from N. 10°W. to N. 55°W.; average trend varies according to locality
Size	A few tens of feet in greatest diameter to 9 miles long and 3 or more miles wide; many average between 1 mile and 3 miles long by 1/2 mile wide	A few hundred feet in greatest diameter to 4 miles long by 2 or more miles wide
Shape	Elliptical Cigar-shaped Rectangular Ovoid or egg-shaped Irregular Triangular Compound	Elliptical, many with one side more strongly curved than the other Ovoid or egg-shaped Irregular
Ratio of length to width	From almost 1:1 to 5:1, many are 2:1 to 3:1	From almost 1:1 to 3-1/2:1
Depth	Exclusive of filling, from less than 10 feet to 60 or 70 feet below surrounding plain	Exclusive of filling, from 1 or 2 feet to 30 or 40 feet below surrounding plain
Shorelines	Major outline of many lakes is smoothly curved; in detail, most lake shores are jagged or rough	Shorelines are smoothly curved
Sand rims	Conspicuously absent	Conspicuous, partial, or complete rim or rims of white or pale buff sand around most, but not all, bays
Drainage	No present subsurface drainage; surface drainage absent from many	Subsurface drainage for all; surface drainage absent from many
Relationship to one another	Lakes parallel, intersect, or overlap one another	Bays parallel, intersect, or overlap one another
Relationship to beach ridges	Clusters of lakes lie between what are interpreted as beach ridges	Clusters of bays lie between what are interpreted as beach ridges
Linear arrangement of lakes	Rows of lakes are present in a few localities	Rows of bays are present in a few localities
Material in Coastal Plain	Permanently frozen gravel, sand, silt, or muck	Sands, sandy loams or marls, limestones, and arkosic sand

Present wind direction in re-	Average wind is from northeast, Winds highly variable and cannot be correlated with trends of bay:
Climate at time of origin	Presumably arctic climate sim- Cold accompanying maximum Wisconsin glaciation
Age	Probably Pleistocene to Pleistocene
	Recent

In the vicinity of Peard Bay and Harrison Bay and at other localities on the Coastal Plain of northern Alaska, clusters of lakes lie between what have been interpreted as beach ridges and are aligned in rows that may have any orientation relative to the axial trend of the lakes. As in the Myrtle Beach area in South Carolina, described by Cooke, such lakes are believed to be the result of uplift and segmentation of lagoons, although the actual processes involved in such segmentation are not clearly understood.

Prevailing winds in the direction of the long axis of the Alaskan lakes are believed to be the chief factor that controlled their orientation. What climatic changes would have to be made to produce a northwesterly (or southeasterly) wind are not known, but presumably they were connected with the major climatic changes during the Pleistocene period and possibly with the most recent uplift of the Brooks Range to the south.

Johnson's hypothesis of the origin of the Carolina Bays "supposes that artesian springs, rising through moving ground water and operating in part by solution, produced broad shallow basins occupied by lakes, about the margins of which beach ridges were formed by wave action and dune ridges by wind action." Such an origin for the oriented lakes of northern Alaska presupposes that the ground was thawed to a considerable depth during the time that the lakes were forming. Whether during one of the warmer interglacial periods known to have occurred in Alaska the ground was thawed sufficiently to permit circulation of ground waters or artesian waters is not known. Evidence for such phenomena should be looked for particularly in the deeper lakes in the southern part of the Coastal Plain. During such a period of thaw, solution might have taken place in Cretaceous limestone beds, some as much as 6 feet thick and totaling about 100 feet in thickness, which are believed to underlie the area. However, the presence of frozen and well-preserved plant and animal remains dating back into the Pleistocene indicates that there has been no long period of thaw since that time.

Whatever the origin, the lakes present an intriguing problem that deserves considerable attention.

The discovery that Mars and Mercury, like the Moon, are heavily cratered (presumably by extraterrestrial projectiles) has caused geologists to search for similar large craters on Earth. The search has been successful, with more "impact structures" and "astroblemes" (star wounds) identified each year. Generally, the larger the crater, the more controversial it is, for many find it hard to accept that our planet has had such a catastrophic past. No one denies the reality of Meteor Crater, in Arizona, but can Hudson's Bay be a crater? And what really was the famous 1908 Tunguska event? This subsection encompasses only the very large and the more peculiar craters.

ETC-001 METEORITE CRATERS AS TOPOGRAPHICAL FEATURES ON THE EARTH'S SURFACE

Spencer, L. J. ; Smithsonian Institution Annual Report, 1933, Government Printing Office, Washington, 1935, pp. 307-325.

Spencer provides excellent geological, and historical descriptions of several large craters, most of which "seem" to be meteoric. There are, however, many peculiar features of some of the craters which make it worthwhile to reproduce this entire report with the exception of footnotes. The Siberian crater especially may have been created by other terrestrial or extraterrestrial means.

The problem of meteorite craters is quite a new one. Until 1927 the only known example was the "Meteor Crater" in Arizona, which since 1892 has been the subject of much discussion and controversy. Various theories have been put forward to explain its origin. The one most generally accepted at the present time is that the crater was formed by the impact of a gigantic meteorite on the earth's surface, but this view still finds some opponents. • Strong support was given to this theory by the discovery made in 1931 of a group of craters near Henbury in Central Australia. But definite proof was finally given by the remarkable discovery made by H. St. J. Philby during his crossing of the Arabian Desert early in 1932. The search for the legendary city of Wabar was graphically described by him at a meeting of the Royal Geographical Society on May 23, 1932. The "walls" of the city were found to be the rims of a series of craters, and the abundant "cinders" of the city "destroyed by fire from heaven" proved on examination to be a nearly pure silica glass. Nearby, rusted pieces of meteoric iron were also found, the largest remnant weighing 25 pounds.

The finding of the silica glass as cindery and slaggy masses and as complete "bombs" was in itself a remarkable discovery, for no similar material had ever been found before, and it was found in great abundance. Silica glass is, in fact, of rare occurrence in nature. It is best known in the form of fulgurites or lightning tubes, which are formed when sand dunes are struck by lightning. Since a temperature of about 1,700°C. is required to melt quartz sand, the development of a large amount of heat is here indicated. Further, the smaller pieces of meteoric iron from Wabar when sectioned, polished, and etched show a partial destruction of the characteristic structure such as can be brought about artificially by heating the material to about 850°C.

Now the close association of silica glass and meteoric iron with a group of craters in a sandy desert can be accounted for in no other way but by the impact of a shower of large meteoric masses. We have, in fact, at Wabar a typical example of meteorite craters.

It is my present purpose to give some account of the few meteorite craters

or supposed meteorite craters that have so far been discovered, in the hope that the scanty information at present available may be of some help to travelers in recognizing further examples. There are many craterlike depressions on the earth's surface, but it would be rash to assume that all have been formed by the fall of meteorites. Some other pieces of evidence must be sought for. Nothing is yet known of the mechanics of the formation of such craters. They are not merely dents or holes made just by the projectile force of the meteorite as hitherto supposed. They appear, rather, to be explosion craters due to the sudden vaporization of part of the material, both of the meteorite and of the earth, in the intense heat developed by the impact.

The meteorite craters so far described may be easily remembered by the following classification, with two examples in each class:

Single craters with associated meteoritic material (Arizona and Texas).

Groups of craters with associated meteoritic material (Central Australia and Arabia).

Groups of craters without associated meteoritic material (Estonia and Siberia).

Single craters without associated meteoritic material (Ashanti and Persia).

This makes a total of eight examples. It seems a pity to disturb this beautifully symmetrical arrangement, but farther on I shall add a third example to the second class, while the third and fourth classes are not proved, and the last example is more than doubtful. That leaves only five more or less certain examples of known meteorite craters.

The Arizona crater was first brought to notice in 1891 by the discovery of many masses of meteoric iron scattered around the crater. The finding of diamond in this iron aroused a considerable amount of interest and not much notice was at first taken of the crater itself. It was known locally as "Crater Mountain" or "Coon Butte", and was afterward called "Meteoer Crater." The irons are known as the "Canon Diablo meteorite" from the Canon Diablo nearby. The locality is situated in Coconino County in the desert of north central Arizona and close to the Santa Fe railroad.

The crater is a basin-shaped depression approximately circular in outline with a maximum diameter of 3,950 feet and a minimum diameter of 3,850 feet, or three-quarters of a mile. Its depth is 570 feet. The outer slopes rise gently from the surrounding desert plain to a height of 130 to 160 feet at the rim, while the inner slopes are steep and precipitous, and partly covered with talus. The bottom is level (410 feet below the plain) with an area of over 300 acres, and was once occupied by a lake as shown by the presence of lacustrine deposits up to 88 feet in thickness. In the surrounding country the beds of sandstone and limestone (of Carboniferous age) are horizontal, but in the walls of the crater they dip radially outward at angles of 10° to 80°, and in one place are faulted. The outer slopes are covered pell-mell with fragmentary material ranging in size from blocks of rock estimated to weigh over 4,000 tons down to the finest "rock flour." Fragments are littered about for a distance of 6 miles from the center, and they were evidently ejected from the crater, the largest blocks being nearest the rim. Indiscriminately mixed with this material, and also buried in it, have been found thousands of pieces of meteoric iron ranging in weight up to 460 kilos (1,014 pounds) and also pieces of laminated iron shale resulting from the weathering of the iron. About 20 tons of the iron has been collected, but inside the crater only four small pieces have been found and relatively little of the iron shale. It is obvious that this meteoritic material must have been ejected from the crater at the same time as the blocks of sandstone and limestone.

Besides diamond, the Canon Diablo meteoric iron contains 7.33 percent of nickel and small amounts of the precious metals platinum and iridium. One

assay gave platinum 3.65 and iridium 14.95 grams per metric ton. It therefore seemed to offer a promising mining venture, the supposition being that the main mass of the large meteorite, perhaps 500 feet across and weighing over 14 million tons, that formed the crater would be found buried inside. Mining claims were taken out by the Standard Iron Co. in 1903 and many trial shafts (6) and bore holes (23) were put down at considerable expense, but nothing of value was found. After passing through crushed and metamorphosed sandstone and abundant rock flour, undisturbed sandstone was met at a depth of 620 feet. The metamorphosed sandstone shows a partial fusion of the grains of quartz and grades into a friable and porous silica glass.

Another company, the Meteor Crater Exploration & Mining Co., was formed in 1927, and a new drill hole was put down through the southern wall of the crater (under the supposition that the meteorite had entered at a slanting angle). After passing through 30 feet of iron shale cementing fragments of metamorphosed sandstone, the drill stuck at a depth of 1,376 feet, presumably against some hard object, which was believed to be the main mass of the meteorite. An attempt was then made to sink a shaft outside the crater to a depth of 1,500 feet from which the mass could be reached by a cross cut, but at a depth of 640 feet a heavy flow of water was encountered and the work had to be abandoned after the expenditure of \$293,000. Attempts are now being made to raise funds for further exploration.

All this work, which has added much valuable detail to a knowledge of the crater, was carried out by the late Daniel Moreau Barringer, of Philadelphia, who was an enthusiastic supporter of the meteorite theory, and it is now being continued by his son, D. M. Barringer, Jr. Under the guidance of Mr. Barringer the crater was examined in detail by the late Dr. George P. Merrill, of the United States National Museum, and eventually he became an adherent of the meteorite theory. Previously this theory had been rejected by G. K. Gilbert, of the United States Geological Survey, in favor of the theory that the crater had been formed by a volcanic steam or gas explosion without the extrusion of any lava. Although there are no volcanic materials in the immediate neighborhood of the crater, yet there are extensive basaltic flows at a distance of 10 miles, and the extinct volcanoes of the San Francisco Mountains are only 30 miles away. There are still supporters of this theory; but it does not explain the intimate intermingling of shattered terrestrial rocks with meteoritic material, nor the presence of silica glass. It would be a strange coincidence for such a volcanic outbreak to take place just at the spot where masses of meteoric iron had previously fallen, and they certainly could not have fallen afterward.

Further, the temperature of a steam explosion would not be high enough for the production of silica glass. The same, and more, objections would apply to the theory that the crater has been formed by the solution of limestone, being of the nature of a sink hole. The crater extends downwards into sandstone, far beneath the base of the bed of sandy limestone.

The Arizona crater, like the craters of Henbury and Wabar, shows an intimate association of meteoric iron and silica glass with fractured terrestrial rocks, and it was undoubtedly formed by the fall of a large meteorite. But whether the main mass of this meteorite still lies buried in the crater is extremely doubtful. More probably such portions as were not vaporized by the intense heat developed by the impact were shot out by the gaseous explosion and scattered around the crater.

The Texas crater is situated about 9 miles southwest of Odessa in Ector County. It is a shallow depression roughly circular in outline with an average diameter of 530 feet. The rim is about 18 feet above the bottom of the hole, but only 2 or 3 feet above the surrounding desert plain where horizontally bedded limestone is exposed. The steep inner slopes show the limestone dipping at 20°

to 30° away from the center. A much-rusted fragment (1,120 grams) of meteoric iron was found here in 1922, and the crater was first mentioned in 1927. Amongst the fragments of limestone and sandstone forming the rim of the crater a few more small pieces of iron have been found together with numerous pieces of iron shale. The various suggestions made to account for the origin of this crater are discussed by E. H. Sellards, namely: (1) volcanic explosion; (2) salt dome; (3) expansion by hydration of anhydrite; (4) explosion of gas; (5) fall of a meteorite. The last is considered to be the most probable, and this view is supported by D. M. Barringer.

The Henbury craters in Central Australia, known locally as the Double Punch-bowl, are situated 7 miles west-southwest of Henbury cattle station on the Finke River, about 50 miles south of the MacDonnell Ranges. Pieces of meteoric iron having been sent from there to the University of Adelaide with the statement that they had been found around craterlike depressions, A. R. Alderman at once proceeded to the locality in May 1931, when he was quick to recognize the importance of the discovery. Within an area of half a mile square he mapped 13 craters, and around them he collected more than 800 pieces of meteoric iron, together with much iron shale and some black glassy material. At one spot over an area of 6 by 6 feet more than a hundred small pieces of iron were picked up. The largest crater is oval in outline, 220 by 120 yards across, and 50 to 60 feet deep. The others are approximately circular with diameters ranging from 10 to 80 yards and depths from 3 to 25 feet.

With their gently sloping outer surfaces the craters are not very conspicuous until one stands on the rim, when the steep inner slopes come into view. The craters are, however, marked out by the growth of mulga trees, acacias, and coarse grass, since they act as collecting pans for rainwater in this arid region (average rainfall, 6 inches per annum). The steep inner walls consist of powdered rock and shattered blocks of sandstone, quartzite, and slate of Ordovician age. Only at one spot in the walls were the rocks seen to be apparently in situ and with the same dip as in the surrounding country. A feature that may perhaps be of some significance was noted by Mr. Alderman around two or three of the craters, but best seen around crater no. 3, which is 45 yards in diameter. Here, radiating from the rim, are five or six low ridges of sandstone, only a few inches in height and varying considerably in length, the average length being about 30 yards. It is suggested that these may have resulted by the percussion of the meteorite. Only two pieces of iron (one of 13 pounds) were found inside one of the craters, and these on the surface just inside the rim. A boring in the floor of crater no. 5 (25 yards diameter) passed through 8 feet of fine silt down to rock fragments, but no iron was found.

A large amount of material, together with much valuable information about the Henbury craters, has been sent to the British Museum by R. Bedford, of the Kyancutta Museum, in South Australia, who visited the locality in June 1931 and May 1932. This includes 642 pieces of the iron with a total weight of 891 pounds (405 kilos). The largest pieces weigh 292, 170-1/2, and 120 pounds, but the majority are small and curiously twisted and curved. A selection of this material is on exhibition in the Natural History Museum at South Kensington. Most interesting is a group of four irons with a total weight of 440 pounds, excavated in 1932 from a depth of 7 feet inside the smallest crater. They were found in contact and with much flaky rust between and around them, and they are evidently the weathered remnants of a single mass. Immediately around and beneath the iron were broken blocks of rock, while the overlying material was fine grained and free from big stones. This crater (no. 13 on Alderman's map) is only 10 yards in diameter and 3 feet in depth; and in this case the explosion was evidently not sufficient to "backfire" the main mass out of the crater. Around the crater 60 small twisted pieces of iron were found, together with fragments of

iron shale, but no silica glass. Excavation of the rather larger 15-yard crater (no. 11) gave a negative result.

The larger blocks of the Henbury iron when sectioned, polished, and etched show the normal lamellar octahedral structure (Widemanstatten figures) of a medium octahedrite. In the smaller twisted and curved pieces the lamellae are bent and twisted. Further, the kamacite is granulated, proving that here the temperature exceeded 850°C. Oxidation of the iron has proceeded along the curved cracks, along which the pieces eventually break up. These curiously twisted and curved pieces therefore seem to be weathered remnants of pieces of the iron which were torn, perhaps in a plastic condition, from the main masses by the force of the explosions. The corroded surfaces and the normal internal structure shown by the larger pieces of the iron indicate that these also are only weathered remnants of still larger masses, in fact merely the cores to which the intense heat had not time to penetrate by conduction. Pieces of iron shale are also found in abundance around the craters. These, especially when found buried, are sometimes clustered together in the form of "shale balls", in which occasionally a core of unoxidized iron still remains.

Silica glass has so far been found only around the largest crater at Henbury, but not in the same perfection and abundance as at Wabar; and, being formed by the fusion of a ferruginous sandstone, it is less pure. It shows a curious distribution on the ground, for which no explanation can be offered. On the west side of the crater larger cindery and cellular masses and pieces of partly fused sandstone are found close to the rim; while on the east side small tear-shaped drops and threads with a smooth, glossy surface are found along a narrow strip of ground extending eastwards a mile from the crater.

At Henbury there must have been not a single mass but a shower of large masses of iron that formed the group of craters. The large oval crater, which shows a promontory on its longer side, was doubtless formed by two masses falling close together at the same time.

The Wabar Craters, discovered by Mr. Philby in February 1932, are in the Rub' al Khali at 21°29-1/2' N., 50°40' E. Two distinct craters were mapped with indications of two others buried in the sand. Isolated patches of the slaggy material suggest that still more craters are buried. The larger crater is approximately circular in outline with a diameter of 100 meters and a depth of 40 feet (10-1/2 meters). It shows a long gap in the rim on the northern side. The smaller crater, 200 meters distant from the first, is oval in outline with dimensions of 55 by 40 meters. The outer slopes are gentle and the inner slopes steeper, and the bottom is filled with drifted sand. For a distance of about 40 meters from the rim the outer slopes are thickly strewn with cindery masses of silica glass and smaller complete bombs of the same material, ranging in size down to small "black pearls", which were picked up in large numbers.

The rims of the craters appear to be built up mainly of this silica glass. There are no rock fragments except as small angular pieces of a sintered sandstone enclosed in the larger masses of silica glass. Near the craters there is a small outcrop of a friable cream-colored sandstone composed of small shattered grains of quartz, and this presumably extends beneath the desert sand and the craters.

On the outer slopes of the craters there were also collected a few small pieces of meteoric iron and fragments of iron rust. A much rusted mass of meteoric iron weighing 25 pounds was found about 200 meters northwest of the smaller crater and nearer one of the buried craters. This must be only a weathered remnant of a much larger mass, as it shows the normal octahedral structure unaffected by heat. In the smaller pieces the kamacite is granulated. The group of craters indicate that here there must have been a shower of large masses of iron.

The reason for the unique development of silica glass at Wabar is no doubt that the large masses of iron fell on clean desert sand. A remarkable feature of the bombs and black pearls is their extreme lightness. Inside they consist of a very cellular white silica glass, and they are coated with a thin skin of black glass, usually with a highly glazed surface and often beset with minute pimples. The black glass is brown and transparent, with only a few minute bubbles, when examined in thin sections under the microscope. Chemical analysis shows it to contain some iron and a small amount of nickel in addition to silica. These structures suggest that there was a pool of molten and boiling silica (the silica vapor causing the highly cellular structure), and that a rain of molten silica was shot out from the craters through an atmosphere of silica, iron, and nickel produced by the vaporization of the desert sand and part (perhaps a large portion) of the meteorite. The minute pimples on the surface were dewdrops from these vapors formed in the last stages.

The group of craters in Estonia are on the Baltic island of Oesel (=Saare Maa) at kilometers northeast of Arensburg (=Kuresaare) on the farm Sail («Kaali») (58024' N., 22°43' E.). They have long been known and often described, first by J. von Luce in 1827. They have been thought to be earthworks made by man, and they have been compared with the crater lakes of the Eifel and the Campi Flegrei. Other modes of origin that have been suggested are that the craters were formed by (1) gas explosions, (2) oozing out of a bed of clay, (3) weathering of limestone, (4) solution of salt or expansion of anhydrite. In 1922 J. Kalkun compared them with the Arizona meteorite crater. Recently, in 1927 again in 1929, a detailed survey with borings and trenches has been undertaken by J. A. Reinvaldt, Inspector of Mines in Estonia, and he comes to the conclusion that the craters were formed by the fall of a shower of iron meteorites. While his work was in progress a visit was made to the locality by E. Kraus and R. Meyer, of Riga, and Alfred Wegener, of Graz, and he freely supplied them with full details and drawings. As a result they published a long joint paper, which appeared only shortly after Reinvaldt's own paper. Kraus inclines to the view that the craters were formed by the solution of the salt in salt domes; but Meyer and Wegener, while considering this mode of origin to be possible, favor the meteorite theory as the more probable.

The main crater, which is occupied by a lake, is nearly circular in outline with a diameter of 92 to 110 meters. Its rim is 6 meters above the surrounding ground, while inside the depth is 15.5 meters. The steep inside walls show beds of dolomite (Silurian age) dipping away from the center at angles of 30° to 40°. Beneath this there is a zone of pulverized rock containing rock fragments; and the rocks at the bottom of the crater are shattered. Five other smaller craters, irregularly distributed over an area of three-fourths of a square kilometer, are described in detail. Four of these are circular in outline with diameters of 10 to 39 meters and depths of 1 to 4 meters. The fifth is oval, 53 by 36 meters, suggesting that two masses of iron fell together. In the bottom of one of these smaller craters the shattered bedrock shows an impression which is believed to represent the dent made by the meteorite. Reinvaldt supposes that the craters were formed by violent steam explosions, steam being suddenly generated from the ground water in the rocks by the heat of impact of the meteorites, and that the meteoric iron was shot out from the craters together with rock fragments. There are indications of other small craters that have been filled with stones collected from the land. A mantle of glacial deposits about a meter in thickness covers the ground. This is intermingled with the rock debris of the craters, proving that the craters are postglacial.

No meteoritic material has been found at this locality. The absence of masses of iron is explained by the fact that the ground has been tilled since time immemorial. But pieces of iron shale should have been found in the excavations

in the rims of the craters. Silica glass would, of course, not be found, as the surrounding rock is dolomite.

The Siberian craters are rather disappointing, showing only as a series of small pools in a swamp. It is certain that some catastrophic event occurred there on June 30, 1908, but its exact nature still remains doubtful. Unfortunately no good and connected account has yet been given, but sensational reports appear periodically in the newspapers. The best account, collected from the available scraps of information, is that recently given by Dr. Whipple. Only after a lapse of several years, in 1921, were inquiries made in the neighborhood of Kansk by Dr. Leonid A. Kulik, who is curator of the meteorite department in the Mineralogical Museum of the Academy of Sciences at Leningrad. A fireball had been seen and loud explosions heard over a wide area, blasts of hot air were felt, and an earthquake recorded at Kansk and Irkutsk, as well as at Tashkent, Tiflis, and Jena. Air waves had also been recorded on the microbarographs at Cambridge, London, Reading, and Petersfield in England, though they were not deciphered until 1930 by Dr. Whipple. Then it was remembered that remarkable midnight glows and twilight had been seen in Europe and Siberia on June 30, 1908, and the following nights. Mention of a "meteorite" [i. e., meteor, for no meteorite has even yet been found] was made by Dr. Kulik and others.

In 1927 and 1928 Dr. Kulik was able to locate the place of the fall, being led to the spot by the devastated forests. Pine trees are felled radially outwards for a distance of 60 kilometers (37 miles) from the center, the area of devastation covering several thousand square kilometers. A fourth expedition was made in 1929-30, when Dr. Kulik spent 20 months at the locality, but his new results are not yet published. He has, however, generously imparted some of the information, and I have to thank him for a long letter of September 1932 and several photographs.

The spot is on the watershed between the streams Khushmo and Kimchu, which flow respectively into the Chambe and Chunya, both tributaries of the Podkamennaya (Stony) Tunguska, at 60°55' N., 101°57' E. The nearest settlement is Vanovara, on the Stony Tunguska, 80 kilometers to the southeast. The center of the fallen forest is near the southern limit of permanently frozen ground, which is here at a depth of half a meter. In winter there is a half meter covering of snow, and the minimum temperature recorded in December 1929 was minus 56°C. In summer it is a region of peat bogs and mosquitoes. The rocks of the region are fine-grained and coarse basalts overlain by glacial deposits and peat. Only on the hills are rock exposures occasionally seen.

In the swamp are numerous round depressions—10 according to some accounts and 200 according to another—ranging in diameter from 10 to 50 meters and up to 4 meters in depth. Around the area of these "craters" the peat is thrown into concentric ridges. A trench cut through one of these ridges showed contorted folds of peat, clay, and ice. Three borings were made to a depth of 31.5 meters at the edge and in the center of one of the round depressions. Under the covering of peat there was permanently frozen clay down to 25 meters, and below that a sandy deposit which was not penetrated.

One view is that these depressions are formed by the freezing of water in cavities between the permanently frozen ground and that frozen only in winter, causing expansion and afterwards bursts. They are said to be of normal occurrence at the southern limit of permanently frozen ground. This view is opposed by Dr. Kulik. Another view is that they were formed by the solution of limestone, salt, or gypsum; but this is at once ruled out by the bedrock being only basalt. Dr. Kulik believes them to be really meteorite craters, though he himself suggests some alternative explanations. They may have been formed by the folding of the surface layers by the blast of hot air, or by flooding following the melting of the frozen ground, or by smaller still warm masses of meteoric iron

lying on the frozen ground. None of these explanations, however, appears to be satisfactory, and it is indeed doubtful whether these small depressions are at all comparable with those of Henbury and Wabar. No trace of meteoric material has been collected by Dr. Kulik, but he was told by the natives that pieces of iron were formerly found in the central area of the fallen forest.

The Ashanti crater occupied by the large circular lake of Bosumtwi lies on a watershed at 6°30'N., 1°25'W. It is roughly circular in outline with a diameter of about 6-1/2 miles and a depth to the surface of the lake of 900 to 1,200 feet. The gentle outer slopes merge into the surrounding upland 300 to 600 feet below the rim, which is higher on the south side. The lake is nearly 5 miles across and 240 feet in depth, and its surface is 600 feet below the surrounding country. Pre-Cambrian phyllites exposed in places in the steep inner slopes show the same strike and dip as in the surrounding country. Granitic rocks, but no volcanic rocks, are present in the neighborhood. The view of the Gold Coast Geological Survey that the crater is due to faulting is not accepted. A gas explosion is not probable, and Dr. Maclaren suggests that the crater was formed by the fall of a large meteorite. But no meteoritic material has been found, and there is no shattering of the rock walls, and no fragmentary material in the rim.

The reader cannot fail to note the frequent lack of meteoric material in the vicinities of large craters.

The supposed crater in Persia was shown to General Dyer in 1916 by his native guide Idu as a curious hole in a level plain near Gwarkuh (28°30' N., 60°40' E.) in the Sarhad district of Persian Baluchistan. The hole was then 150 feet long, 120 feet wide, and 50 feet deep with absolutely perpendicular sides. Idu said that it had been only half its present size, but twice as deep, and that his grandfather remembered how and when it was made. The old man told him that one night, when he was a youth, something exploded in the sky, and falling to the earth had punched a hole 100 feet deep in the plain. The spot was visited by C. P. Skrine in 1921, who gives the dimensions as 95 by 70 feet, with a depth of 35 feet. At the time of a later visit in 1929 it had silted up by 3 feet. The picture given by Skrine shows a vertical hole through horizontal strata (apparently alluvial deposits), and it does not in the least suggest a meteorite crater.

But what caused it?

The Campo del Cielo craters in Argentina may now be added to the list of known meteorite craters. The locality is situated in the Gran Chaco on the border between the Province of Santiago del Estero and the Chaco Nacional, and around the railway station Gancedo (27°28' S., 61°30' W.). Native iron has been known from this district since 1576, when it was discovered by Hernan Mexia de Miraval. Rubin de Celis in 1783 saw a mass which has been variously estimated to weigh 13-1/2 to 45 metric tons, and a few large masses have since been collected. One weighing 1,400 pounds was presented to the British Museum by Sir Woodbine Parish in 1826. At the place is a group of round and shallow depressions (hoyos or pozos), the largest, 78 by 65 meters, being occupied by a lake, the Laguna Negra, the rim of which rises only 4 feet above the surrounding level pampa. These have recently been examined by Dr. J. J. Nagera, the chief geologist of the Argentine Survey, and excavations were made in the hoyo called "Rubin de Celis" (also called "Pozo del Cielo").

This is circular with a diameter of 56 meters and a depth of 5 meters. Pits dug in the rim and in the center of the depression showed disturbed beds of sandy loess mixed with "white volcanic ashes" and "transparent glass in angular,

curved, and striated pieces." There are no volcanic rocks in the surrounding parapa, and the Andean volcanoes are 500 miles away. The transparent glass, if examined, would most probably prove to be silica glass. Small fragments of rusted meteoric iron were found in one of the pits near the rim of the hoyo. A piece of typical iron shale (very similar to that from Henbury) from this excavation was presented to the British Museum by Dr. Antenor Alvarez in 1927, but unfortunately none of the glass was sent. Dr. Nagera concludes that the hoyas were not formed by the fall of the masses of meteoric iron, but that they were made by man. There seems, however, little doubt that they are really meteorite craters. They are easily accessible and close to the railway, and should certainly be further investigated. There are other suggestive features worthy of investigation in this district. Many small lakes and pozos are scattered around; and in particular a chain of small lakes extends southward from the spot where the large masses of meteoric iron have been found for a distance of nearly 100 miles into the province of Santa Fe.

Summary of Characters of Meteorite Craters. The following tabulation of the dimensions of the described craters shows that there is a very wide variation in the ratio of width to depth. This ratio must be rapidly affected by denudation, and perhaps gives some indication of the relative age of the craters. This ratio will also depend on the type of rock, as shown in the two mine craters of La Boisselle and Hill 60.

	Width, feet	Depth feet	Ratio of width to depth
Texas	530	18	29.4
Ashanti	34,300	1,300	26.4
Siberia	164	13	12.5
Campo del Cielo	183	16	11.4
Estonia	33	3	11.0
Do	128	13	9.9
Do	300	50	6.0
Henbury	30	3	10.0
Do	240	25	9.6
Do	360	60	6.0
Wabar	328	40	8.0
Arizona	3,900	570	6.8
Hill 60, Ypres	340	67	5.1
La Boisselle, Somme	270	70	3.8

From the above accounts it will be seen that a certain amount of direct evidence is supplied only by the craters of Arizona, Henbury and Wabar, and this has to be supplemented by a considerable amount of speculative deduction. Direct observation of how such craters are formed is, of course, quite out of the question. Meteorites of which the fall has been actually observed have always been of comparatively small size, and their velocity has been reduced by the resistance of the air to that of an ordinary falling body of about 70 meters per second. They make small holes, usually of not more than 1 or 2 feet in depth, in the ground. The largest meteorite of which the fall has been observed is a stone of 820 pounds, which fell at Paragould in Arkansas on February 17, 1930. This penetrated clayey soil to a depth of 8 feet, scattering clods to a distance of 50 feet in the pasture. On the other hand, the largest known meteorites, all of

which are irons and none observed to fall, have been found by reason of their being partly exposed at the surface of the ground. The 60-ton Hoba meteorite discovered in South-West Africa in 1920 has its upper surface level with the surrounding ground, and around it there is no sign of a crater. The large masses of iron near Cape York in the north of Greenland were found loose on the rocky surface.

It seems therefore that meteorite craters are not merely dents in the ground made by the percussion of a meteorite; but that they are explosion craters due to the sudden vaporization of part of the material, both of the meteorite and of the earth, in the intense heat developed by the impact. When a large mass of iron traveling with planetary velocity is suddenly stopped, the kinetic energy ($1/2mv^2$) is transformed into heat at a localized spot with the development of a very high temperature. Simple calculations give very high figures.

The materials from the Henbury and Wabar craters give ample evidence of high temperatures. The transformation of kamacite from α -iron to γ -iron at 850°C . and the melting points of iron at $1,530^\circ\text{C}$. and silica at $1,700^\circ\text{C}$. are definite points on such a "geological thermometer." We may further add the boiling point of iron at $3,200^\circ\text{C}$. and that of nickel at $3,377^\circ\text{C}$., but this is probably too low. These are the boiling points calculated for the pressure of one atmosphere, but under the enormous pressures produced by the explosions at the meteorite craters they must have been considerably higher.

The upward force of the explosion must be very much greater than the downward force of percussion; and for this reason the beds exposed on the inside crater walls will dip radially outwards from the center (fig. 3a), instead of inward toward the center as might at first sight be expected. The outward dip could also perhaps be explained as in figure 3b, where a ring anticline has been formed by the percussion. The inner walls of the crater are always much steeper than the outer walls. The rim and outer slopes are formed of the fragmentary material shot out from the crater, and the amount of this material and the size of the blocks will show a gradual decrease with the distance from the center. Some of the fragmentary material would also fall back into the crater and so cover up the shattered rock at the bottom. The known meteorite craters are all approximately circular in outline and their inner and outer slopes are symmetrical about the center; that is, the craters are figures of rotation about a vertical axis. This is as would be expected in the case of an explosion crater; but in the case of a percussion crater it would happen only when the projectile strikes the surface normally.

The most likely place to search for meteoric iron would be on the rim and outer slopes, where much will be buried, perhaps to be exposed later by weathering processes. Meteoric iron readily oxidizes and breaks up. Buried fragments will give rise to the formation of more or less compact iron shale and shale balls, and these may be expected to be more persistent than the iron itself. Silica glass can be formed only when the rocks surrounding the crater are highly siliceous, such as quartz sand or sandstone.

Natural and Artificial Analogies. Basin-shaped depressions, often occupied by lakes, are common enough on the earth's surface, and they may be formed in several different ways. Volcanic craters and especially caldera (formed when the upper portion of a volcano is blown away by a violent explosion, or by subsidence of the cone) may be very similar in form to meteorite craters, but being composed of volcanic materials they are quite distinct. But in the case of explosion craters (or "embryonic volcanoes") an explosion of steam and volcanic gases may give rise to a crater consisting entirely of fragments of sedimentary rocks without the outpouring of any lava. Examples of these are the "maars" of the Eifel. The Pretoria salt-pan (3,400 feet across and 400 feet deep), 25 miles north-northwest of Pretoria, and Lonar Lake on the basalt plateau of the Deccan,

have been thought to be such explosion craters; but the former presents more points of resemblance to a meteorite crater than does, for example, Lake Bosumtwi. Explosions of gas may also take place in oil-bearing regions, sometimes with the formation of mud volcanoes.

The craters on the moon are usually thought to be of volcanic origin, but the suggestion has also been made that they were formed by the fall of meteorites. Their large size is perhaps related to the smaller force of gravitation. If the meteoritic theory is here true, we can only hope that the earth is not approaching the same stage.

Craters may also be formed on the earth's surface by the solution of beds of limestone, or of pockets of rock salt or gypsum.

As noted above, the craters of Estonia and of the Campo del Cielo have been considered by some authors to be earthworks made by man. This suggests that some other supposed earthworks may possibly be really meteorite craters. Many dew ponds are clearly artificial, but some supposed to be of Neolithic age may possibly have been formed by the fall of meteorites. As examples of large holes made artificially in the earth's surface mention may be made of the diamond mines at Kimberley and the still larger Premier diamond mine near Pretoria.

A closer analogy is given by the craters formed by military mines and high-explosive shells. The mine crater of La Boisselle, on the Somme, exploded on July 1, 1916, was 270 feet in diameter from rim to rim and 70 feet deep. The rim consisted of debris piled up to a height of 15 feet above ground level and the outer slopes extended to 90 feet beyond, the total diameter being 450 feet. In this mine two charges of 36,000 and 24,000 pounds, laid at 60 feet apart and 52 feet deep, were fired together. The positions of the two charges are shown on figure 3c by the dotted squares. They formed a circular crater of greater depth than the charges. One of the craters on Hill 60, near Ypres, was 340 feet across the rim, and 67 feet deep; here there was one charge of 70,000 pounds of ammonal. These dimensions are comparable with those of the Henbury meteorite craters, but the craters here were in much softer rocks—chalk at La Boisselle and Eocene sand and clay at Hill 60. A photograph of a devastated area on the Aisne in France, showing numerous water-logged shell holes and stripped trees, is extraordinarily similar to one of Dr. Kulik's photographs of the Siberian craters, only much more impressive.

As examples of much smaller craters produced by artificial means mention may be made of the splashes of drops (also rain on mud flats), clay balls thrown on a slab of clay, and shots on armor plates.

ETC-002 THE SIBERIAN METEORITE

Merrill, George P. ; Science, 67:489-490, May 11, 1928.

One of many descriptions of the famous "Tunguska event. "

In view of recent newspaper reports regarding a great meteorite supposed to have fallen in Siberia, I am sending you the following rather free translation of Mr. L. Kulik's story as it originally appeared in Russian.

From the two newspaper articles by Mr. L. Kulik, which you gave me, I have been able to obtain the following information concerning the so-called "Tungusk meteorite."

The appearance at 7 o'clock in the morning on June 30, 1908, of a "fiery body" of unusual brightness, rolling across the sky out of the northeast and falling down in the "taiga" between the Yenissei and Lena Rivers, north of the Railroad line, was observed by a great number of people, mostly the native inhabitants, living in the basins of these rivers.

The fall of the meteorite was instantly followed by a column of fire rising skyward, by the formation of the heavy black clouds, and by a most deafening, resounding noise far surpassing in its magnitude, any thunderstorm, or artillery cannonade. This was heard for hundreds of kilometers within a radius of the cities of Yenisseisk, Krasnoyarsk, Kansk, Nijneudinsk, and Kirensk on Lena.

A terrific air-wave was formed which pushed ahead everything that it met in its way. The water in all rivers, lakes and streams was raised up; people and animals were lifted by it and carried along.

The vibrations produced by the fall of the meteorite were detected and registered by the seismographs of the Physical Observatory at Irkutsk, where Mr. A. V. Vesnesenski, who was in charge of the observatory, calculated the epicenter of the "earthquake" to be located in the upper part of the Podkamennaya Tunguska.

The phenomenon produced considerable panic, especially among the natives living in the basins of the Yenissei and all the various Tunguska Rivers, and adjacent part of the Lena River basin.

Several attempts, made in 1908, to find the body of the meteorite were fruitless, as for some reason all parties were searching near the city of Kansk, and not in the locality, determined by A. V. Vesnesenski, whose observations unfortunately remained unpublished. Gradually interest in the new meteorite died, and the whole matter was almost forgotten, except as a tale among the natives.

In 1927 Mr. L. Kulik attempted to find the exact location of the meteorite and led an expedition to the Tungusk region. Owing to the lack-of funds and the extreme difficulties of transportation in the wilderness of taiga and tundra, the expedition was not altogether successful. However, Mr. Kulik was able to reach the area where the taiga bore distinct traces of the passage of the meteorite. An area struck by the meteorite is a water table between the upper part of the Podkamennaya Tunguska and its right tributary the River Chuni. The area is largely covered with tundra in the process of formation, intersected by hills, small lakes, swamps and typical tundra. The immediate area is surrounded by high naked hills, deforested by the falling meteorite. All trees are still on the ground, their tops are spread out in fan-like fashion away from the central zone of the fall. Exceptions are noted only in the ravines or in the gorges and deep perpendicular valleys and also in a zone which can be considered as the "interference" zone. And even in these places the trees, in most cases, are scorched and though still in upright position they are all leafless and dead.

The zone where the heat effect of the meteorite is evident is considered by L. Kulik to be 30 kilometers in diameter and the area of the air-wave breaking the trees is 50 kilometers in diameter.

The central part of the "fire zone" is covered by shallow "funnel" shaped craters, reaching in some instances many tens of meters in diameter and not greater than 4-5 meters in depth. The bottom of the craters is covered with swampy growth.

Unfortunately, Mr. Kulik was not able to find the body of the meteorite or determine the depth to which it had sunk.

He believes that the meteorite of 1908 was an aggregate (a swarm) of meteors, moving with a rate approaching 72 kilometers a minute. Some of the aggregates

undoubtedly exceeded 130 tons in weight. Hot gases (above 1,000°C.) surrounded the meteorite and started fires before the meteorite had reached the ground and sunk into it, forming craters, uprooting the trees and burning everything that can burn in the center of its fall.

ETC-003 DID A COMET COLLIDE WITH THE EARTH IN 1908?

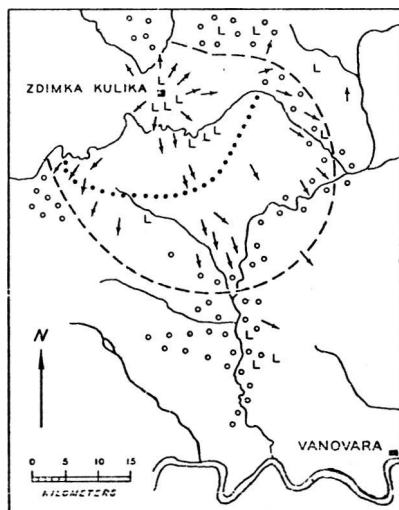
Florensky, Kirill P. ; Sky and Telescope, 26:268-269, November 1963.

The Tungus Meteorite Expedition of the U. S. S. R. Academy of Sciences recently returned from central Siberia, where it investigated the area of the fall of the famous Tungus meteorite of 1908. This expedition was the third in a comprehensive study of the locality, the others being in 1958 and 1961.

The historic event of June 30, 1908, was a tremendous explosion near latitude 61° north, longitude 102° east, in a highly inaccessible region that was not visited by scientists until 1927. Over an area 30 kilometers in radius, every tree had been blown down, pointing outward from the center of the area. The "visitor from space" had exploded over the taiga forest, leaving no traces except for those toppled and burned trees.

For many years, various expeditions kept searching for debris of the meteorite near the epicenter of the explosion. But was this the proper place to hunt? When a great explosion occurs, the updraft of heated air can lift debris to a great altitude, after which the mushrooming cloud may drift downwind, produc-

In the upper left of the author's sketch map is the ground center of phenomena connected with the Tungus bolide. Fires caused by the explosion spread as far as the line of dots, and trees were felled out to the dashed circle. Arrows indicate their directions of fall, mostly radial to the ground center. An L symbol indicated dead trees still standing, while open circles mark existing old forest.



ing slow fallout. It actually turned out that 60 to 80 kilometers northwest of the epicenter there was a concentration of meteoritic dust. Was this material the remains of the Tungus meteorite, or just ordinary micrometeorites? The 1962 expedition sought the answers to these questions.

We investigated the distribution of cosmic dust over a large territory, charting the pattern of its dispersal. Our task was greatly facilitated by using a helicopter, for ground travel is slow in this quite thinly inhabited subarctic region.

Also, we collected material for chemical analysis. At the expedition's base camp in the taiga, we set up a concentration mill, to separate an infinitesimal admixture of extraterrestrial matter from numerous bags of soil samples. Gradually the picture began to take shape, as the outlines of the dispersal pattern became more and more distinct. Magnetite particles, which cannot be mistaken for anything else, were being found in the soil.

After surveying 60,000 square kilometers, we could trace the narrow "tongue" for nearly 250 kilometers northwest from the site of the explosion. We believe it extends even farther.

What kind of material did we find?

Every day thousands of tons of extraterrestrial dust, composed of magnetite (magnetic) and silicate (glassy) particles, settle on the earth's surface. The most easily recognizable cosmic particles are tiny brilliant spheres, less than 0.1 millimeter in size. Their appearance shows they were formed in the atmosphere as molten matter congealed. Most of them are meteoritic remnants.

The Soviet meteoritist Evgeny Krinov proved that such spheres can also be produced during the flight of a meteorite through the atmosphere (Sky and Telescope, September, 1959, page 617). The air tears off the thin, molten surface film, and the fog of droplets of iron or stone congeals into tiny spheres. During the explosion of a large body traversing the atmosphere, a part inevitably melts to produce such spheres. Occasionally we found two spherules fused together, which indicates that the Tungus meteorite was not of uniform composition. We brought thousands of such particles back to Moscow.

As far back as the 1930's, the Soviet geochemist Vladimir Vernadsky contended that the Tungus meteorite had actually been a dense cloud of cosmic dust, possibly associated with a comet. This viewpoint is now confirmed. The material we have collected is of added interest in offering the chance to study cometary debris in the laboratory.

Our expedition has determined the flight course of the Tungus object more closely than before. The eyewitness accounts from 1908 had not settled this problem. Both the general pattern of the toppled trees and the relationship between the centers of fallen deadwood and the searing effect—as well as the distribution of cosmic dust—indicate that the object came from east-southeast. This fact is strongly in favor of a comet-type orbit.

On the critical day in 1908, the approach of the comet would have been invisible, because it was moving across the daytime sky. The collision was neither head-on nor a stern chase, for the Tungus object struck the earth almost squarely on the side.

It has sometimes been suggested that the great cataclysm over Siberia was a nuclear explosion, on the basis of reported radioactivity in deep rings of fallen trees from the area. Our expedition investigated this question very carefully, and established that this radioactivity is fallout from modern atomic bombs, which has been absorbed into the wood. There is nothing specific in the nature of the radioactivity in the area of the Tungus fall.

The living trees in the Tungus area gave valuable new information. We found that branches which had been not thicker than a fountain pen before the catastrophe still retained marks of their injuries. It was possible to pinpoint the location of the explosion as five kilometers above the earth's surface, south-

east of the center of destruction on the ground.

Why did the thicker branches escape injury? The inner bark of thin twigs could not protect the living cells of the cambium from heat, but the coarser bark of thicker branches gave more protection. Thus, we infer that only enough heat was radiated to warm the living cambium to 60° or 70° Centigrade, while setting fire to dry grass and brush. At more than nine or 10 kilometers from the epicenter there are no traces of heat radiation effects. However, the forest fire naturally raced farther out along the prepared bed of fallen trees.

After 1908, the forest began to grow more rapidly in the devastated area than in surrounding regions. Biological field parties which had worked there in 1961 have completed their study of this. Their conclusion is that only the normal acceleration of second growth after fires had taken place. The meteorite had played only an indirect part in this acceleration.

Should we call the celestial body that fell on June 30, 1908, a meteorite or a comet? Actually both terms are correct. A meteorite is any cosmic body that has fallen to Earth. The majority of known meteorites are stone or iron bodies of asteroidal origin. However, if a comet strikes the earth, it too becomes a meteorite.

Many facts favor the view that the colliding object was a comet: the unusually loose structure, which led to breakup in the atmosphere; the dust tail, pointing away from the sun, that caused unusual sunsets over nearly all Europe; the nature of the orbit; and lack of big fragments.

The explosion in the earth's atmosphere is readily explained. The sudden stopping of a body moving at five kilometers per second releases enough heat to vaporize it instantaneously, even if the body is iron or stone. During deceleration in the air, part of the released energy heats up the body, another part produces a shock wave.

If the body is loosely compacted, deceleration is much more abrupt and so is the energy generation. Moreover, if the object contains volatile matter, such as frozen gases or ice, deceleration in the air may cause explosive vaporization, without the body striking the ground.

According to modern ideas, the nucleus of a comet is just such a loosely compacted ball of cosmic dust, cemented by frozen gases. Also, comets contain free radicals that are stable only at very low temperatures, and which react with explosive violence when heated.

Annual meteor showers, such as the Perseids, have long been known to result from the collision of cometary debris with the earth. It is noteworthy that meteorites have never been known to fall as part of an annual shower; it seems that comets contain few sizable iron or stone masses.

ETC-004 THE HOLLEFORD CRATER IN ONTARIO

Beals, C. S., et al; Sky and Telescope, 15:296, May 1956.

The Holleford crater is a circular depression approximately 100 feet deep and 1-1/4 miles in diameter. The village of Holleford is located partly within its boundaries, and easy access is provided by several roads that cross the rim or descent near the floor of the crater, as shown by the accompanying photograph. [Not reproduced]

ETC-005 CRATERS AND ASTROBLEMES

The southern and southwestern parts of the rim are reasonably intact and form an impressive cirque of nearly 180 degrees, whose shape appears not to have been altered greatly by erosion. Other parts of the rim have been deeply eroded, and successive strata of limestone have been exposed, which indicates the probability that the original crater was buried under sedimentary deposits.

Most of the interior of the crater consists of farm land underlaid by limestone gently dipping toward the center, but an irregular inner area (dark on the photograph) is a wooded bog. Older geological maps, as well as a recent investigation by M. J. Frarey of the Geological Survey of Canada, identify the sedimentary covering of the crater as of Ordovician age.

Examination with the stereoscope, which greatly exaggerates the relief, has shown that the inner slopes of the Holleford crater are much steeper than the outer, a characteristic of explosion craters. The actual slopes are relatively gentle; it seems clear that the original form of the crater has been greatly altered, certainly by the deposition of sediments and subsequent erosion and probably by erosion prior to deposition.

If subsequent investigation should reveal the crater to be of meteoritic origin, it would be one of the largest known. It is slightly larger than the recently discovered crater of Talemzane in southern Algeria, but still much smaller than the Ungava crater or the Brent crater in Canada.

ETC-005 BOSOMTWE: AN AFRICAN METEORITE CRATER?

Anonymous: Sky and Telescope, 30:15, July 1965.

In Ashanti Province, Ghana, there is a water-filled crater 10.5 kilometers (6-1/2 miles) in diameter, with a rim that rises about 140 meters (460 feet) above the surrounding plain. It is called Bosomtwe, meaning "sacred antelope" in the Twi language. The formation is unique in Ghana, and has few counterparts anywhere on Earth. There is no other lake within nearly 1,000 kilometers in this part of West Africa.

The remarkable similarities between Bosomtwe in Africa and a large man-made crater in Canada have been studied by G. H. S. Jones and C. H. H. Diehl of the Suffield Experimental Station, Ralston, Alberta. The Canadian object was made by the surface explosion of 500 tons of TNT. This produced a depression 100 meters across, with a central mound, temporary lake, several circumferential and radial cracks, and a number of slump terraces. Some of these features are unusual in artificial craters, but not uncommon in natural ones on the earth and moon.

In shape Bosomtwe and the 500-ton crater are strikingly similar. The former is 100 times larger in both average diameter and in rim height. The Ghana crater does not now have a central island, but its lake is shallow and silt may have filled in the original basin.

The main circumferential crack from the Canadian explosion is 64 meters from the center, and a less complete but equally distinct set of curved fractures is at 79 meters. The scale factor of 100 indicates that corresponding topographic features should be sought between 6.4 and 7.9 kilometers from the center of Bosomtwe. In this zone there is in fact a striking system of drainage channels, formed by the Banko, Tetredu, and Ahiresu-Buonim rivers. They

comprise a nearly circular band that goes at least three quarters of the way around the crater.

One and possibly several radial cracks characterized the Canadian crater. In Ghana, the Buonim water channel leaves the crater area along a fairly straight line that is approximately radial.

How much energy was required to form Bosomtwe? As a first approximation, the energies needed for two geometrically similar craters are in the same ratio as the cube of their scale factor. On this basis, Bosomtwe corresponds to $(100)^3 \times 500 = 500$ million tons of TNT. Thus it appears that the Ghana crater could have been produced by the impact of a meteorite several hundred meters in diameter, having a velocity of the order of 10 kilometers per second.

It is not known how old Bosomtwe is. But since the lake is completely encircled by a watershed, and has no outlet, it may be possible to estimate its age from the salinity of the water.

During a recent visit to the area, Dr. Jones was informed by the chief of the Ghana Geological Survey that a small magnetic anomaly was detected in an aerial traverse of the Bosomtwe region.

Note that the Bosomtwe (or Bosumtwe) crater is sometimes associated with the Ivory Coast tektites.

ETC-006 MOON, EARTH IMPACT SIMILARITIES STUDIED

Anonymous; Aviation Week, 44+, June 17, 1974.

Terrestrial counterparts of lunar impact craters have been an objective for both Earth Resources Technology Satellite and Skylab orbital photography. This includes known sites, like Meteor Crater southeast of Flagstaff, Ariz., and discovery of previously unknown sites. Some surprising results have followed. One is the appearance of a ray-like structure around Meteor Crater. Rays are long-term, sharply defined features on the moon, but were not expected to persist in the erosional environment on earth. Craters at top center are volcanic cinder cones in the Sunset Crater field. Lava flow fronts are discernible around the cones in this Actron Industries S190B mapping camera photo from Skylab. One of the buttes in area is southwest of Meteor Crater. Another surprising result from study so far is the dearth of any new impact structures, despite the inference from lunar and planetary terrains of intense bombardment in early planetary history. Experimenters at the same time have become sensitized to the hunt for circular impact structures, the vast number of which are formed other than by impact. Interest in these has grown, despite the lack of new impact sites, because of associations of ore deposits with some previously unrecognized circular features, (p. 44)

Previously unrecognized circular structure was spotted and photographed by crew of final Skylab mission with hand-held Hasselblad camera in oblique view. Snow cover defined the structure in this case, although its circular shape is not so pronounced in planview from directly overhead. Part is outlined by the Chippewa River, in Wisconsin, which flows into the Mississippi River that flows through area in lower left of photo. The broad area is ore-rich, with the Mesabi iron range northwest of Duluth, Minn., and copper, first discovered by the Indians on the Keweenaw peninsula of Michigan, on the south shore of Lake

Superior. Lake Nipigon, Canada, also has a circular shape but is not included in lists of Canadian impact sites. LaCrosse, Wis., and part of Iowa are south and west of the circular structure. In photo at right, Vredefort dome in South Africa is considered a possible impact site. The Bushveldt complex is considered by Paul D. Lowman, Jr., a Goddard Space Flight Center planetologist, as a possible terrestrial counterpart of lunar mare basins. (p. 45)

Manicouagun impact site in Canada is about 50 km. (31 mi.) in diameter and one of the largest known on earth. Its moat-like outline was photographed by Skylab astronauts. Circular features in South West Africa could be mistaken for impact sites but are products of internal melting on earth. ERTS photo of the Munich area includes the Ries impact site. Its vaguely outlined diameter is about 25 km. (15 mi.). One of the more recent impact site discoveries lies west of Brazil's capital, Brasilia. This is the Araguainha Dome about 40 km. (24 mi.) in diameter. Its double ring structure is closer in configuration to lunar three-ring craters than most terrestrial impact sites. Presence of impact melt and shatter cone patterns in rocks there, considered fingerprints of the intense pressures and temperatures of impacts by meteorites, identified this site as this type of crater, (p. 47)

The last two paragraphs are from photograph captions. Note the immense sizes of the craters under discussion.

ETC-007 WHAT BORED THESE HOLES?

Fuller, Curtis; Fate, 17:10-12, October 1964.

Something else from the sky is responsible for a mystery near Plainview, Tex., where two Texas Tech professors can't seem to agree on the nature of the object that gouged out a series of holes in a cotton field last May 11. The holes are on the Doodle Milton farm 25 miles east of Plainview.

The main hole is 18 inches in diameter and it is surrounded by smaller holes which gave the appearance of having been drilled. A kind of white residue is clinging to the sides of the holes.

One Texas Tech professor believes the holes were made by a meteorite that "burned up completely."

An alternate theory proposed by Dr. William T. Parry, professor of geoscience, is that the mysterious holes were produced by a lightning strike on the ground. Such holes are called fulgurites.

However, most fulgurites are smaller than those on the Milton Farm.

The holes have been dug out and their side channels traced without revealing any further evidence of what might have caused them.

Similar excavations are also reported in the Series G sourcebooks, where ball lightning has apparently been involved.

Several types of evidence are presented in this subsection. First, there are the abundant indications that sealevel has risen and fallen small amounts—hundreds of feet—within the time of man. Then, the submarine canyons and guyots suggest that sealevel was several thousand feet lower in relatively recent geological time. Finally, bits and pieces of continental crust seem to have foundered, Atlantis-like, and now reside in deep water. The latter two classes of evidence, in particular, suggest unconventional terrestrial scenarios.

ETE-001 EMERGENCE AND SUBMERGENCE OF LAND

Geikie, Archibald; Nature, 70:111-115, June 2, 1904.

This summary of Geikie's address to the Geological Society contains an excellent description of the famous raised beaches and "parallel roads" of Great Britain.

Let any observer who has followed the great 50-foot raised beach along the western coast of Scotland and up the Linnhe Loch to the mouth of the Great Glen, look away to the right hand where the wide Strath of Spean leads into the interior. While yet standing on the platform of the raised beach, if the air be clear, his eye may detect the beginning of a line, drawn as with a ruler, at the same height along the slopes on either side of the valley. This is the lowest of the three great Parallel Roads of Glen Roy, and runs at a height of 850 feet above the level of the sea. If he will now ascend into Glen Roy, where the three terraces are best seen, he will soon be struck by the distinctive differences between these old lake-margins and the raised beaches with which he has already made himself familiar. In the first place, he will remark their faintness as compared with the marine platforms of the coast. Though readily traceable from a distance in their horizontal continuity, they are in many places hardly discernible when one is actually standing upon them. A little examination soon reveals that each of them has been produced mainly by the arrest of sediment washed from the slopes above into the water of the vanished lake. Instructive illustrations of this process may often be observed along the sides of reservoirs which have been constructed in steep-sided valleys: there each prolonged halt of the water at a particular level is marked by a shelf of detritus which, blown in by wind and washed down the declivities by rain, is stopped when it enters the water, where it accumulates as a miniature beach.

Here and there, especially on more exposed projections of the hillsides, there has been a little cutting-back by the shore-waves or drifting ice-floes of the old lake in Glen Roy. Occasionally also, where a streamlet has entered the water, its arrested detritus has accumulated as a broad, flat delta or terrace. But it is manifest that, in such limited expanses of water, wind-waves could have had comparatively little erosive power. Nor can we imagine that, even if the water froze, its floe-ice could have had any potent influence in sawing into the rocks of the declivities, and producing seter or rock-shelves. Certainly throughout this wonderful assemblage of lake-shores, there is nothing for a moment to be compared to the incised platforms of rock so abundant as part of the raised beaches of the western coast of Scotland. We must remember also that the production of such ice-dammed lakes took place as a mere episode in the retreat of the ice. No means are available to determine what may have been the length of time during which the water stood at the level of any one of these Parallel Roads. We may probably infer, from the absence of well marked and continuous intervening shore-lines, that the shrinkage of the ice and the consequent

ETE-002 EMERGENCE AND SUBMERGENCE

lowering of the level of the water were somewhat rapid.

The Parallel Roads of Lochaber, although the most imposing, are not the only examples of the shore-lines of ancient glacier-lakes in this country. Another striking case is that of Strath Bran in Ross-shire, where the glaciers descending from the mountains on each side ponded back the drainage of the valley, and sent it across the present watershed of the country at a height of about 600 feet above the sea. The conspicuous gravel-terraces at Achnashean are a memorial of this vanished sheet of water.

Now, with these undoubted records of ancient lakes, let us compare the structure and distribution of our Raised Beaches. These shore-lines are found, on both sides of Scotland, at approximately the same heights above the level of the sea. They are partly terraces of deposit, and partly true seter or platforms cut out of the solid rock, the same beach presenting frequent alternations of both structures. In general, it may be said that the detrital terraces are found chiefly in bays, sea-lochs, or other sheltered places, while the rock-terraces are conspicuous in more open sounds and exposed parts of the coast, where the tidal currents and wind-waves are most powerful.

As the highest terraces are the oldest, they have been longest exposed to the influences of denudation, and are thus the faintest and most fragmentary. But the dimensions and perfection of a raised beach do not depend merely on age, but in large measure on the length of time that the water stood at that level, and the varying local conditions that favoured or retarded the planing-down of solid rock or the deposition of littoral sediment.

That these beaches unquestionably mark shore-lines of that sea may be inferred on three grounds:-(1) Their position on both sides of the island at corresponding heights. No possible arrangement of ice-dams in the Atlantic and in the basin of the North Sea can be conceived that would have everywhere ponded back the land-drainage to similar levels. (2) Their independence of local conditions. The same terrace may be traced down both sides of a sea-loch and round the coast into the next loch, retaining all the while its horizontal continuity. Not only on the mainland, but on the chain of islands outside, the same parallel bar has been incised, both on the inner or sheltered side and also on the outer flank looking to the open Atlantic. (3) Their organic remains. From the youngest of the beaches up to the highest, the terraces of deposit contain marine organisms which have not been scooped out of some earlier formation, but lie in the positions in which the animals died, or into which they were washed by shore-waves and currents. The fossils of the latest beaches are entirely identical, or almost so, with forms still living in the adjacent seas, while those of the higher beaches are boreal or Arctic.

In some sheltered places, such as the Dornoch Firth, especially near Tain, and some inlets on the west side of the island of Jura, a number of successive bars or terraces of deposit may be observed up to heights of 100 feet or more above the sea. But there are in Scotland three strand-lines so conspicuous and so persistent that attention may be confined to them. From what has been taken to be their average height above mean sea-level or Ordnance-datum, they are known respectively as the 100-foot, the 50-foot, and the 25-foot beaches.

ETE-002 RISING OF THE LAND AROUND HUDSON BAY

Bell, Robert; Smithsonian Institution Annual Report, 1897, Government Printing Office, Washington, 1898, pp. 359-367.

p.

In the Provinces of Ontario and Quebec it has been found from actual levelings by Gilbert, Spencer, and Upham that the old shore lines are not perfectly horizontal, but that they slope upward in a northeasterly direction at rates varying in different regions from a few inches to a foot and even 2 feet per mile. If this upward slope were continued in the same direction to the northeastern extremity of Labrador, 1,300 miles from Lake Huron, the increase in the elevation might there amount to 1,000 or 2,000 feet. It is scarcely probable that the differential elevation is constant and regular for such a great distance. Still, it is a fact that well-preserved shore lines are to be seen at great heights in the northern parts of Labrador. In my Geological Survey Report for 1884 I have mentioned ancient beaches at Nachvak, 140 miles south of Hudson Strait, which have an estimated altitude of 1,500 feet above the sea.

The two sides of Hudson Bay present very different physical characters. The eastern is formed mostly of crystalline rocks, and, as a rule, is more or less elevated, with a broken surface sloping somewhat rapidly westward or toward the bay; while the western side is mostly very low and much of it is underlaid by nearly horizontal Silurian and Devonian strata. These low shores are accompanied by shallow water extending far to seaward. The head of James Bay, which forms the southern prolongation of Hudson Bay, is extremely shallow, but the various rivers which flow into it have cut channels through the soft shallows, and by means of these the land may be approached with seagoing vessels. The whole of Hudson Bay may be said to be shallow in proportion to its great area, as the soundings show that it does not average more than 70 fathoms in depth.

The shores of the bay everywhere afford abundant evidence that there has been a comparatively rapid rise in the land and that the elevation is still going on. I have mentioned numerous proofs of this in my various official reports on the geology of these regions from 1875 to 1886, and I shall now recall a few of those and give fresh ones in addition, some of which came to my knowledge on a journey to the bay during the past summer. It is well known to those who have paid any attention to the subject that since the establishment of the posts of the Hudson Bay Company in the mouths of the rivers around the bay, two hundred years ago, there has been an ever-increasing difficulty in reaching these establishments from the sea.

On the eastern side the most striking evidence of the rising of the land is afforded by the numerous well-preserved and conspicuous terraces cut in the till and other deposits. Near the sea these may be seen at various heights, up to about 300 feet, but above this elevation the scarcity of soft material out of which terraces might be excavated renders this kind of evidence less apparent than it might otherwise be at higher levels.

On this side of the bay one of the best evidences that the elevation of the land is still going on is furnished by the long lines of driftwood which one sees in many places far above the reach of the highest tides.

The old beaches, on which this wood is plainly seen, occur at various levels up to about 30 feet above high tide, but the remains of rotten wood may be detected in some localities up to nearly 50 feet, above which it has disappeared from the ancient shores by long exposure to the weather. This driftwood consists principally of spruce, but a little white cedar and other kinds, which have been brought down by the rivers, are also mixed with it. The bark having been worn off by the action of the waves while the trunks were still fresh has tended to their preservation. Owing principally to the salt water and the cold climate, wood endures for an incredibly long time in exposed situations in this region wherever it has an opportunity of drying quickly after rain. Some of the wood which may still be seen upon the higher levels may be upward of six hundred years old.

It has been suggested that all this driftwood along hundreds of miles of coast

ETE-003 EMERGENCE AND SUBMERGENCE

may have been thrown up by some extraordinarily high tide. But there are many reasons why this is quite unlikely. It seems impossible that any modern tide could rise to such a great height and deposit so much wood at different levels all at once and in such even lines, following all the sinuosities of more than one of the raised beaches. The suppositious extraordinary tide would necessarily be of brief duration, and would be accompanied by a tremendous gale blowing upon the coast. This would have the effect of throwing the wood in confused heaps and only into situations favorable for catching it, such an angles of the shore. But instead of this we find it at different levels laid longitudinally all along, as if accumulated by slow degrees with moderate winds from every quarter. The fact that the wood is freshest along the lower lines and becomes progressively more decayed as we ascend, and that finally only traces remain on the higher levels, shows that it must have been stranded from time to time as the land was rising above the sea, and we are forced to adopt this obvious view of the case, (pp. 359-361)

See Hess' paper [ETE-0061 on the drowned Pacific islands (guyots).

ETE-003 CHIPS OFF THE PLATES

Anonymous; Nature, 227:767-768, August 22, 1970.

This summary of Glomar Challenger findings presents evidence of foundering continental material In the Atlantic—geological echoes of Atlantis perhaps. The dating of course is incompatible with Plato's Atlantis, but how good is the dating?

Scientifically, the cruise has collected cores from several fragments of continental material left behind by the opening of the north Atlantic, has shown that the Gulf Stream once flowed Into the Labrador Sea, and unexpectedly has revised the date of the commencement of the last glaciation. The continental fragments are evidence that the break between North America and Europe was not as clean as that producing the jigsaw fit between Africa and South America. Greenland was also left behind, but Iceland Is a purely volcanic island built up from the mid-Atlantic ridge. To begin with, cores were recovered from Orphan Knoll, an isolated seamount just beyond the continental shelf near Newfoundland, and the deepest core recovered was a black sandstone containing fragments of anthracite that might have been laid down In a river bed, showing that the seamount was once a low-lying continental fragment. The same kind of evidence was unearthed from the Rockall Plateau, and Drs. Laughton and Berggren say that they have enough data from two boreholes to give a chronological history of the sinking of the plateau after it separated from Greenland 56 million years ago. But why these two regions should be disappearing into the seabed—at a rate of one foot every thousand years for the Rockall Plateau during the last of the three stages of sinking that have been Identified—Is still a mystery.

And here follows a revision in Ice Age chronology.

Two boreholes in the Labrador Sea contained layers of rock fragments, at a depth corresponding to 3 million years ago, that are believed to have rained down on the seabed from melting icebergs. Dr. Laughton said that this is an earlier date than previously thought for the beginning of the last glaciation in

the North Atlantic. It corresponds to the middle of the Pliocene, and is the first strong evidence that the glaciation was earlier than the boundary between the Pliocene and the Pleistocene, 1.8 million years ago. Beneath the glacial debris, the cores contain subtropical organisms showing that before the glaciation the Gulf Stream was probably flowing along the Labrador coast.

ETE-004 EVIDENCE OF FOUNDERED CONTINENTAL CRUST BENEATH THE CENTRAL TYRRHENIAN SEA

Heezen, B. C., et al; Nature, 229:327-329, January 29, 1971.

The first paragraph of this article summarizes the situation very nicely—pieces of continental crust may have dropped far below the present sea level.

The dredging of schists, phyllites and marbles from the faulted margin of a tilted crystal block in the central Tyrrhenian Sea shows that the acoustical basement beneath the centre of this sea basin includes a sequence of rocks similar or perhaps identical to the Palaeozoic and Triassic schists and phyllites of the adjacent Apennine, Calabrian and Sicilian chains, the Pontian Islands and Sardinia. Even the low to medium grade metamorphism observed must have occurred beneath the Earth's surface and following metamorphism and deformation we infer that these rocks were uplifted, denuded by subaerial erosion and finally foundered more than 3,000 m below sea level. The Neogene subsidence is still continuing. The metamorphic rocks obtained from the Tyrrhenian acoustic basement appear to support the former existence of the Tyrrhenides and indicate that this ancient upland was underlain by continental crust.

ETE-005 A NEW PACIFIC CONTINENT FORMING?

Anonymous; Literary Digest, 86:25-26, September 5, 1925.

The United States is slowly acquiring a new continent. "Land waves on the bottom of the Pacific Ocean, caused, perhaps, by northward slipping of the Antarctic ice-cap and fortified by pressure from the American coast, the Japanese Archipelago, Alaska and the Aleutian Islands, breaking, at last, on the deep foundations of the Hawaiian Archipelago, seem now to be creating new land among the various islands and shoals of Hawaii." So, at least, says Edwin Fairfax Naulty, geophysicist, of New York, who has made a study of the oceanography of the seven seas over a period of years. He is thus quoted in the New York Times:

"There need be no cause for alarm, as it is unlikely that there will be a violent upheaval. The process is slow and steady and has already been at work for generations. Just now there seems to be unusual activity, and recent soundings show low shoals where only a few years ago the deep-sea lead gave great depths. This is particularly true of the region lying between Maui and Midway and of the famous Penguin shoal off Molokai.

"The expected upthrust of land, which is likely to come in this generation,

will present as a gift of nature to the United States a territory in the mid-Pacific as long as from San Diego, California, to Queen Charlotte Sound, British Columbia, and as wide as California, or as long as from the tip of Florida to Boston, Massachusetts. Such a territory, based on the present population of Java of 36,000,000, would easily support a population of at least 25,000,000. It would be of tremendous strategic advantage to the nation holding it as a productive and trade base, and would grow enough sugar, rubber, copra, coffee and tea to render the United States independent of other present sources of these articles.

"Great changes have been and are taking place in the bed of the Pacific Ocean. These changes are reflected in the seismic instability of all the coasts surrounding that vast deep. The modern epoch of these changes seems to have begun with the volcanic upheaval, itself the result of a remoter cause, that blew up the mountain of Krakatoa in Sunda Strait, on August 27, 1883, the effects of which were felt around the world, and to have continued through lesser outbreaks to the major disturbances of San Francisco, in 1906, Japan in 1923, and to present seismic activity. The last disturbance, of July, 1925, extended from Kansas, west overland and under the Pacific as far as Honolulu.

"Recent soundings of the channels between the various islands comprising the Hawaiian Archipelago, from Hawaii Island to Midway Island, show shallows of 24 fathoms in old depths of 2,357 and 2,429 fathoms between Kauai Island and Nihoa shoal; a new shoal of 12 fathoms between Nihoa and Necker Island shoal, with soundings midway of 20 fathoms against former 550 and 941 fathoms; of 57 fathoms between Necker Island shoal and French Frigate shoal against former soundings of 1,950 and 1,075 fathoms, of upthrust at Brooks shoal, Gardner Pennacles, St. Rlgotien bank; a new bank, the Raiti (P.D.) and new shoalings around Dowsett and Maro reefs; the extension of Laysan Island shoal, with 13 fathoms depth; a new reef, just awash, to the south of Neva shoal, with a new bank of 25 fathoms depth to the east and a 14-fathom sounding between Pearl and Hermes shoal and Midway Island.

These shoalings extend from Kauai to Kure, from 160 degrees west to 178 degrees west and from 22 degrees north to 28 degrees north, or as latitude mileage runs at that position, for over a thousand miles. It is evident from a check on past observations and reports that the shoalings of the last decade between the islands and between islands and older shoals and the upthrust of old shoals is not an isolated nor local phenomenon, but extends over a considerable area and partakes of the nature of seismic movement of slow motion but great scope. That the movement described has not earlier been noted and correlated has nothing to do with the facts in the case. The failure of seismographs to record it is due to the method of operation of earthquake recorders which announce shocks only and ignore gradual movements of the earth's crust.

"Were we dealing with theory only all this might be interesting only casually, but there are the stubborn facts of the shoalings around the Hawalls. Land growth where there has been no land is not a casual thing."

ETE-006 DROWNED ANCIENT ISLANDS OF THE PACIFIC BASIN

Hess, H. H.; American Journal of Science, 244-772-791, 1946.

Abstract. Some one hundred and sixty, curious, flat-topped peaks have been

discovered in the Pacific Basin between Hawaii and the Marianas. They appear to be truncated volcanic islands rising about nine to twelve thousand feet from the ocean floor. The flat summit levels generally range from three to six thousand feet below sea level. Some less well-developed ones are deeper. The flat upper surface is commonly bordered by a gently sloping shelf a mile or two wide. The summit surfaces are apparently not all of the same age since adjacent peaks may have flat tops which differ in elevation by as much as a thousand feet, though in some cases groups of peaks do have the same elevation. The relationships to atolls of the Marshall Islands group indicate that the surfaces are older than the atoll formation. An hypothesis is tentatively advanced suggesting that the summit surfaces are very old and possibly represent marine planation surfaces in a Pre-Cambrian ocean in which reef building organisms did not exist. It is suggested that the present depths of the surfaces may be accounted for by the relative rise of the ocean surface as a result of accumulation of sediments on the floor. Thus the deeper the surfaces are the greater their age.

Note that the higher the raised beaches are in the polar regions, the older they are—just the opposite of the drowned Pacific islands. See EBS-001 and ETE-001 for examples. The Pacific "guyots" are so important in formulating the earth's history that some further excerpts from Hess' paper are desirable.

Part I. Description. A large number of curious, flat-topped peaks have been discovered scattered over millions of square miles in the Pacific basin. These peaks are roughly oval in plan and their slopes suggest volcanic cones. The remarkable feature about them is that they are truncated by a level surface which now stands approximately 750 fathoms (4500 feet) below sea level. For convenience in discussing these submerged flat-topped peaks which rise from the normal ocean floor, the writer will henceforth call them "guyots" after the 19th century geographer, Arnold Guyot.

Betz and Hess (1942) discussed the major features of the floor of the North Pacific. This was in the nature of a broad areal reconnaissance of the largest features of this extensive region. Since 1942, Hess has spent two years at sea in the western Pacific and has thus had the opportunity to fill in some details which bring to light many new relationships and necessitate some modification of ideas originally set forth. The data presented in this paper were obtained on random traverses incidental to war-time cruising on the U. S. S. Cape Johnson. What passed beneath the ship was recorded but it was not feasible to investigate further such interesting features as were encountered. Nevertheless it is evident that much information can be obtained on the geological history of an oceanic area by judicious use of available techniques. It is a vast and intriguing field for research under more auspicious peace-time conditions.

Scope of Present Investigation. From random sounding traverses across or merely grazing guyots an attempt will be made to construct a picture of their physical features. The data collected on the cruises of the Cape Johnson have been supplemented by soundings obtained from the files of the Hydrographic Office, U. S. Navy. The origin and age of the flat upper surfaces of guyots represent the main problem of this paper. Secondly the relation of guyots to atolls of the northern Marshall Islands will be discussed.

Areal Distribution of Guyots. The distribution of known and suspected guyots is shown in Fig. 1. Roughly they are known to occur north of the Carolines and east of the Marianas and Volcano Islands between latitudes 8°30' North and 27° North and longitudes 165° West to 146° East. None has been found west and south of the above boundaries though this area has been at least as well explored as the former. North and east of the region outlined above it appears from scat-

tered soundings that the area containing guyots does extend to 45° North and 165° West. Some of the seamounts in the Gulf of Alaska described by Murray (1941) almost certainly are guyots whereas others appear to be of a different character. Twenty bona fide guyots were encountered at sea by the writer and some 140 more are indicated by soundings on Hydrographic Office charts and documents. Considering sparseness of deep sea soundings in parts of the area mentioned above, it is likely that a large number of undiscovered ones are present.

Physical Features of Guyots. One of the best profiles obtained across a guyot was one encountered south of Eniwetok on October 6, 1944, in latitude $8^{\circ}50'$ North, longitude $163^{\circ}10'$ East. This guyot is about 35 miles in diameter at the base, and the truncated upper surface is about 9 miles in diameter. The top is remarkably flat at a depth of 620 fathoms. * The outer rim of the top is bevelled by a gently sloping shelf one or two miles wide (slope 2° to 3°). The outer margin of the gentle slope is about 70 fathoms deeper than the inner margin. This gentle slope breaks abruptly to 22° at its outer margin. The profile from the edge of the shelf to the normal ocean floor at 2600 fathoms is, as might be expected, concave upwards. From an average of 22° at the top it gradually decreases in steepness until it forms a smooth tangent with the ocean floor at the bottom. Figure 2 (A and B) below is a reproduction of the sounding traverse across the guyot.

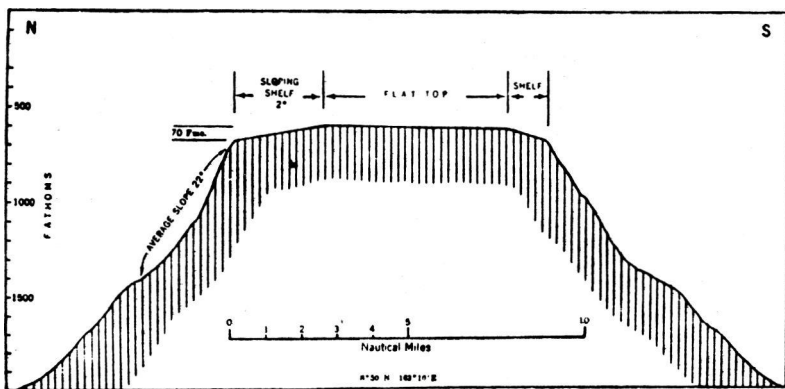


Fig. 2B. Tracing of a fathometer record of a typical guyot, showing the characteristic flat, supposedly wave-eroded, top.

Guyots vary widely in size. One a few miles northeast of Eniwetok has a flat summit only a couple of miles across (latitude $11^{\circ}45'$ North, longitude $162^{\circ}55'$ East); whereas one some distance farther northeast apparently has a flat upper surface 35 miles wide and has a diameter of 60 miles at its base (latitude 14° North, longitude $167^{\circ}30'$ East). In general they appear to be circular or oval in plan. No correlation has been noted between the depths of the flat upper surfaces and the depths of the surrounding ocean floor which normally ranges from 2600 fathoms (15,600 feet) to 3100 fathoms (18,600 feet). The observed depths of the flat upper surfaces of typical guyots range from 520 fathoms (3120 feet) to 960 fathoms (5760 feet), with most values concentrated near the center of this group (800 fathoms). Thus the guyots rise from 10,000 to 15,000 feet above the ocean floor. The flat tops of guyots in general do not exhibit accordance of summit levels. It is quite common to find groups of guyots in a relatively small area with flat tops varying several hundred fathoms from one to another among the group. Less commonly two or three guyots in a group will have approximately the same depth.

A few guyots were found to have upper surfaces which were gently undulating rather than flat. These undulating or hummocky surfaces have a maximum relief of about 40 fathoms. In most cases the flat surface can be seen here and there in the profiles and it passes beneath the hummocky material (Fig. 3). Judging from the evidence most guyots have been swept clean of the fine sediments which must be continually settling upon them. In the case of the rare, hummocky ones it would appear that the fine precipitates had for some reason not been completely swept off. It is rather surprising that the normal guyots are swept clean since water currents at such depths as these are thought to be slight. One must look to occasional bottom stir up by tsunami (Bucher 1940) though possibly currents related to tides might be strong enough. Once the sediment on these isolated, flat-topped peaks is stirred up, very little of it would be expected to fall back on top of the guyot. It would be dispersed over the surrounding area.

Though few guyots show any suggestion of terraces on their outer slopes, one large guyot near latitude 20° North, longitude 148° East has a well developed flat upper surface at 800 fathoms and projecting from under its southeastern margin there appears to be a terrace or older guyot with a flat upper surface at 1100 fathoms. In the area between Wake Island and Johnston Island there are a number of normal guyots rising from hilly areas which have numerous flat or nearly flat surfaces between 1100 and 1900 fathoms. These hilly areas with flat or nearly flat surfaces have as yet been insufficiently explored to understand the relationships they exhibit. They may represent areas of older, deeper guyots partly buried by sediments, but until a more detailed examination of them can be made, their nature will have to remain rather obscure. Such areas do not appear to be common elsewhere. Some of Murray's Gulf of Alaska seamounts possibly also fit into this category. The great majority of guyots rise from the normal ocean floor, (pp. 772-779)

1 Note: All soundings mentioned in this paper are uncorrected for salinity, temperature and pressure and were taken with fathometers set to a speed of sound in the sea water of 4800 feet per second. The corrections would be too small to be of significance in this discussion.

ETE-007 EMERGENCE AND SUBMERGENCE

ETE-007 POLAR RISE AND EQUATORIAL FALL OF SEA LEVEL

Eardley, A. J. ; American Scientist, 52:488-497, 1964.

Eardley produces geological data from all continents—drowned valleys and coasts, raised beaches, and the like—arriving at the following conclusions—

There has been a fall in sea level in the low latitudes and a rise in the high latitudes since the Cretaceous. The amount of fall in the equatorial regions is about 600 feet, and the amount of rise in the polar regions is probably greater than 600 feet. These data may help determine the rate of slowing of rotational velocity of the earth, and also yield something about the strength of the earth.

The gradual change in land and sea areas may have brought on the ice age.

Obviously a uniformitarian, Eardley assumes a slow change in the rate of rotation, but could it not have been rapid, as in an encounter with a celestial body ?

ETE-008 MOUNTAINS UNDER THE MEDITERRANEAN

Anonymous; Nature, 228:199-200, October 17, 1970.

Another example of young sediments overlain by older deposits is reported below from the Mediterranean floor.

Fresh Information about the geological history of the Mediterranean Basin has been gleaned during the most recent stage of the National Science Foundation's Deep Sea Drilling Project (DSDP). On Its voyage through the Mediterranean between August 13 and October 6—leg 13 of the DSDP—the Glomar Challenger collected twenty-seven corings from fourteen sites. Part of NSF's broader National Ocean Sediment Coring Programme, leg 13 was planned by an advisory panel of JOIDES, the Joint Oceanographic Institutions for Deep Earth Sampling.

According to Dr. Kenneth J. Hsu, speaking in Paris on October 9, Glomar Challenger's scientific team recovered "long cores of sediments and rocks astonishingly similar to those found in many parts of the Alpine chains of Europe and North Africa". Using these cores It will be possible, for the first time, to compare the nature, age, thickness and sequential relationships of the material of the ocean with those of the surrounding land.

Signs were detected that in at least two places sedimentary formations have been displaced from their original sites of deposition beneath the floor of the Mediterranean. In one case, in the Hellenic Trough, 120 million year old Lower Cretaceous limestones were found immediately above young, soft Pliocene oozes not more than a few million years old. In another place, north-west of the mouth of the Nile, a huge thickness of abyssal sediments (1-2 million years old), originating in the Nile River, was found upheaved on the submarine Mediterranean Ridge. "These circumstances represent the embryonic stage in a development process," Dr Hsu noted, "which when continued for millions of years will lead to the formation of mountains from the oceanic crust." It seems that Africa and Europe are pressing towards each other and squeezing the Mediterranean sea smaller and smaller, causing parts of the oceanic crust to rise and form mountains.

Mima Mounds, pimpled plains, pingos, and hillocks by other names are widespread in North America. Differing theories of origin are as common as the mounds themselves. Are they the work of the Ice Age, pocket gophers, the Deluge, or some combination of these, or some geological force not yet conceived. These natural (?) mounds should not be confused with the man-made (?) mounds described in the STRANGE ARTIFACTS series of sourcebooks.

ETM-001 PIMPLED PLAINS OF EASTERN OKLAHOMA

Knechtel, Maxwell M. ; Geological Society of America, Bulletin, 63:689-700, 1952.

Knechtel does not believe the pocket gopher theory (ETM-002). Rather, he feels that mound formations are more closely related to the patterned ground of the Arctic regions.

Introduction. Low-relief topography, or microrelief, formed of innumerable closely spaced small hummocks or mounds, is a conspicuous feature of many large tracts of nearly level to gently sloping land in some states west of the Mississippi River, as well as in some other parts of the world. Figure 1, based on a map constructed by Price, shows a number of physiographic provinces wherein such mounds are reported to occur in the United States.

Such mounds are known as "prairie mounds", "hog-wallows" (California), "Mima mounds" (Washington), and "puffs" (Australia). The origin of the mound-studded surfaces, which in this country are commonly called "pimpled plains"

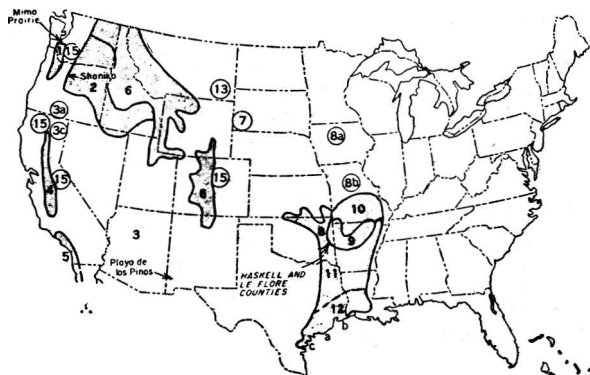


Fig. 1. Map of United States showing geomorphic provinces in which pimpled plains occur. (1) Puget trough; (2) Columbia plateaus; (3) scattered localities in Basin-and-range province; (4) California trough; (5) Pacific Border terraces; (6) southern Rocky Mountains; (8) areas in Central Lowlands; (9, 10) Ozark-Quachita region; (11, 12) parts of Gulf Coastal Plain; (13 and probably 7) river terraces at low altitudes in the Great Plains.

has been a subject of much discussion for more than 100 years and has been attributed to various natural processes. Interpretations of their genesis set forth in the references cited involve such concepts as erosion by networks of rivulets, erosion by wind, "mud-volcano" phenomena, hydrostatic pressure of ground water, "concretionary action", frozen-ground phenomena, construction by ants, termites, rodents, or aborigines.

The diversity of interpretations suggests that such natural-mound systems may have originated in various ways. Eventual agreement may nevertheless be attainable with reference to the origin of individual systems, or groups of systems, particularly where one and the same example of mound relief has been ascribed to different and seemingly incongruous processes. For instance, mound systems near Puget Sound, Washington, were attributed by Newcomb and Pewe to melting of ice wedges in networks of vertical fissures; Dalquest and Scheffer believed them to be the work of pocket gophers. It is scarcely possible that both concepts would survive a thorough-going analysis of the controversial phenomena involved. In other cases, interpretations based on dissimilar processes may prove to be essentially combatible—a contingency implicit in the writer's working hypothesis relating to the pimpled plains of eastern Oklahoma which seems to harmonize not only with the suggestions of Newcomb and Pewe, but also with the soil-erosion hypothesis of LeConte.

The Pimpled Plains of Eastern Oklahoma. Pimpled plains are extensively developed in the Arkansas River valley and the Ouachita Mountains. They appear on airphotos as multitudinous small, rather uniformly spaced, bright or dark patches of ground, most of which are subcircular. The center of each patch coincides approximately with the apex of a mound 2 to 4 feet high. The distance from center to center, generally between 50 and 100 feet, is rather uniform for any one locality, and commonly the margins of the patches are separated by approximately half that distance. Locally, however, the patches are much broader than the interspaces and are of various polygonal shapes.

Many road cuts expose the materials of the mounds and the surfaces on which they rest. A typical mound consists of loess-like material that is partly clay and contains small pellets of limonite, as well as a few subangular fragments of sandstone lithologically like that of local bedrock units of Pennsylvanian age. Most of the rock fragments are 2 inches or less in greatest dimension and are distributed at random. The loesslike material rests with a sharp contact on a flat, nearly level floor that commonly consists of heavy clay, or claypan, lighter in color than the material composing the mound. In places the floor material approaches the consistency of hardpan. The origin of the materials of the mounds and the deposits immediately underlying them calls for more study and is not dealt with here. Additional information concerning them, including a number of mechanical analyses and descriptions of soil profiles, is given by Knobel, Boatright, and Boatright in describing the Conway very fine sandy loam and the Le Flore silt loam, the only mound-forming soil materials mentioned among the various units shown on their map.

The writer has commented as follows upon the bedrock associated with the pimpled plains of eastern Oklahoma, their range of altitude and the time of their origin:

"Many of the mounds occur within areas of bedrock exposure but their areal distribution bears no direct relation to that of any of the different bedrock units. Some of them occur also on ancient gravel terraces and others on the higher parts of the Recent alluvial plains along the larger streams. . . . Those in Le Flore County occur at altitudes ranging through several hundred feet though they are present only on nearly level surfaces and gentle slopes. For example,

on the gently sloping upper surface of a prominent hogback a mile south of Bokoshe mounds occur approximately 400 feet above the Arkansas River level; within half a mile of these and 300 feet lower are others on the higher parts of the alluvial plain along Buck Creek.

"Clearly, the mounds on all such plains were formed since the region attained essentially its present stage of geomorphic development and can therefore scarcely be older than late Pleistocene."

Evolution of the Mound Relief. General Statement. While pimpled plains are ordinarily described as comprising vast numbers of small mounds, they can with equal accuracy be treated as great systems of interconnecting furrows. Such surfaces are here described largely in relation to the intermound furrow systems. The patterns discernible in such furrow systems, when correlated with certain concepts having to do with erosion, offer promising clues to the evolutionary history of the mound relief. Similar patterns have been reported frequently in literature concerning frozen-ground phenomena, but the present discussion stresses origin of such patterns under circumstances that do not involve frigid climatic conditions. A working hypothesis that is offered for the eastern Oklahoma mound relief identifies the furrow patterns as fissure-polygon networks caused by shrinkage without reference to temperature and attributes the relief to attendant subsidence and subsequent erosion of the ground along and adjacent to the fissures.

Summary. The pimpled plains of eastern Oklahoma are evidently assignable to a category of surficial phenomena, sometimes called Polygonboden, which in some parts of the world includes features attributable to permafrost. The intermound furrow networks visible on airphotos of localities in eastern Oklahoma are comparable in pattern and coarseness of texture to the great polygonal networks of ice-filled fissures that commonly form in perennially frozen ground, but the eastern Oklahoma patterns bear an equally close resemblance to those of fissure networks caused elsewhere by desiccation and are comparable in some respects to intermound furrow patterns that appear to have originated, in some other parts of the United States, as a consequence of columnar jointing in the bedrock under the furrows. The data at hand offer little, if any, support to the possibility that the Oklahoma patterns are associated in origin with jointing in bedrock; they do, however, appear to establish desiccation as a possible agency in the origin of these patterns.

The transformation from systems of prismatic blocks enclosed by fissures to systems of mounds comparable to those of the pimpled plains may, apparently, be accomplished by one or more of three processes: (1) expansion of material that accumulates in the fissures; (2) subsidence of the ground along the fissures; and/or (3) erosion by rivelets which may form along the fissures. Assuming that the intermound furrow systems of eastern Oklahoma are related in origin to systems of fissure polygons due to desiccation, the mound relief there may be attributable to widening of grooves that have resulted from subsidence of the ground along the fissures of the polygonal networks.

Because the mound systems are present at various altitudes and occur locally on alluvial surfaces close to the present stream levels, the mound relief of eastern Oklahoma is probably not older than late Pleistocene.

ETM-002 MOUNDS AND PIMPLED PLAINS

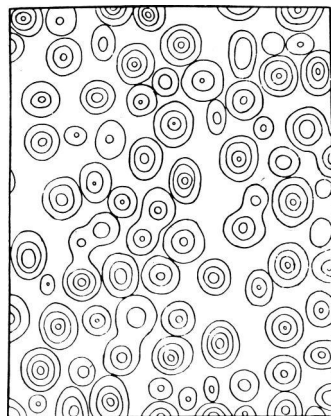
ETM-002 THE MYSTERY OF THE MIMA MOUNDS

Scheffer, Victor B.; Scientific Monthly, 65:283-294, October 1947.

This is one of the classic articles on the Mima Mounds. However, the reader should be warned that many scientists do not concur with Sheffer's "gopher theory", as subsequent entries will prove.

On the prairies of western Washington near the southern tip of Puget Sound are scattered thousands of large earth mounds whose origin has puzzled observers for more than a century. On Mima Prairie some of the mounds are higher than a man's head and have a content of 50 cubic yards. The mounds are smooth and round, like great spheres nearly buried in the earth. In many cases, the hollows between the mounds are filled with cobblestones up to the size of a foot-ball. In the spring of the year, when the mounds are covered with white-and-yellow daisies and green bracken ferns, they stand out clearly from their duller surroundings.

Mound topography. Characteristic arrangement of mounds on Mima Prairie; contour interval, two feet.



Wherever a mound has been sliced open by a roadway, a peculiar cross section is revealed. The typical mound is made up of soft black prairie silt mixed with pebbles up to the size of a walnut. The mound rests in a slight depression, or bed, in coarse, stratified glacial gravel, which continues downward for an unexplored distance. Thus, the typical mound is a biconvex lens, with the greater curvature exposed to the sky and the lesser curvature pressed against the gravel. At the base of the mound, armlike structures of black silt extend into the gravel. These have been called "mound roots" by certain investigators.

The origin of the mounds has long been disputed. A few years ago, a student at the University of Washington suggested a novel theory to account for the mounds and invited me to join him in a search for supporting evidence. How we approached the problem and attempted to fit our findings into a convincing pattern has been described in a preliminary paper.

As we delved into the mystery of the Mima Mounds, it dawned on us that these formations are kindred to similar, though less spectacular, mounds strewn by the millions over the Western states from the Mexican border to northern Washington. Thus, the theory accounting for the mounds of Puget Sound—which we now accept—embraces also the countless mounds of similar shape and structure in the Western states. Because of certain peculiar features, Mima Prairie has served as a Rosetta stone in explaining the origin of other mound prairies.

More than a century ago mound prairies drew the attention of travelers in the new West. In July 1842, Commander Charles Wilkes made a special trip to "Bute Prairie," south of Olympia, Wash., and dug into three of the mounds in an attempt to unlock their secret. He finally concluded that "they bear the marks of savage labour, and are such an undertaking as would have required the united efforts of a whole tribe." As indeed they would!

On the famous railroad survey of 1853-56, naturalists Gibbs and Cooper examined some of the mounds, and Gibbs suggested that "they might have been produced by the immense growth of the 'giant root,' (Megarhiza (Echinocystis) Oregana), forming a nucleus around which the soil has been gradually washed away." Cooper—a more conservative scientist—believed that the mounds were perhaps the result of eddy and whirlpool action at a time when the prairies were submerged beneath Puget Sound. When Gibbs returned to the East he described the mounds to Louis Agassiz, who "unhesitatingly" pronounced them the nests of a species of sucker. Professor Agassiz may be forgiven this opinion in view of the fact that he had not seen the mounds, some of which rise to a height of seven feet.

Joseph LeConte, geologist of the University of California, first saw the Puget Sound prairies in 1871. He was the first to point out the similarities among the mounds in California, Oregon, and Washington and he tried to show that their origin was due to "surface erosion under peculiar conditions." As he reconstructed their geological history, the prairies were left by a retreating body of water with a blanket of fine topsoil and a coarse subsoil; erosion started to remove the finer topsoil everywhere but in certain spots; weeds, shrubs, and ferns immediately seized upon these spots, or islands, and anchored the soil; then when the climate grew drier, vegetation was able to survive only on the higher (and richer) islands while erosion continued to gnaw at their bases.

Interest in the American earth mounds was aroused in faraway England, Geologist Alfred R. Wallace discussed a letter from his brother in California describing the "hog-Wallow" region of the San Joaquin Valley.

The surface thus designated [he wrote] may be represented on a small scale by covering the bottom of a large flat dish with eggs distributed so that their longer axes shall lie at various angles with one another, and then filling the dish with fine sand to a little more than half the height of the eggs.

The California brother attributed the mounds to "innumerable rills that issued from the retiring sheet of ice" of a glacier long since disappeared. (It is now well established that the San Joaquin Valley was at no time covered by ice.

Soon afterward, G. W. Barnes discussed the small hillocks that lie on the old sea terraces back of San Diego. He concluded that the San Diego mounds were produced—and are still being produced—by a peculiar combination of wind and water erosion in the presence of vegetation, as follows: prevailing winds deposit dust and leaves at the base of a shrubby desert plant; rain-water erosion cuts faster at the base of the mound than at the top; the shrub eventually dies; and, "deprived of its protection, the summit is reduced and the base widened as it is lowered, till finally a remnant of the deposit has become so assimilated and compact as to constitute a more permanent summit." Accom-

parried by Dr. K. O. Emery, I examined the San Diego mounds in 1943 and found them very like the mounds of Puget Sound.

In a resume in 1905, J. C. Branner disposed of a number of theories to account for the Western mounds and concluded: "The ant-hill theory seems to me the most plausible, but with our present knowledge it is far from satisfactory." He also dwelt on the concept that the mounds are the result of differential solution and concretion on a large scale.

Marius Campbell, of the Geological Survey, followed shortly with a paper summarizing the various hypotheses for the mounds that lie on the plains from Arkansas to the Pacific coast. He showed that naturalists had laid the origin of the mounds to the agency of humans, burrowing mammals (ground squirrels, gophers, and prairie dogs), ants, fishes, water erosion, chemical solution, wind action, physical and chemical segregation, glacial action, uprooted trees, and spring and gas vents. Campbell suspected the importance of burrowing mammals and ants, especially the latter, although he confessed his inability to understand their methods of operation.

In 1913, J. Harlan Bretz, of the University of Washington, published an article on glaciation of the Puget Sound region and therein described his careful studies of Mima Prairie. He concluded that the mounds were probably the result of water and ice action. In retrospect, it seems logical that Bretz should have associated the mounds with glacial activity since the region under scrutiny, where the mounds are better developed than anywhere else in the United States, marks also the farthest point reached by the Vashon Glacier, last of the Western ice sheets.

Ellis and Lee, in 1919, laid the origin of the San Diego mounds to "the action of wind as it sweeps through the sparse desert vegetation and blows away the loose soil except where it is held by plant roots." These investigators, like certain others before them, apparently did not realize that wind-built mounds are invariably oriented with the direction of the prevailing wind, whereas the mounds in question are either round or, if elongated, are aligned in no common direction.

The theory has been suggested, with variations, that the great power of freezing water has been instrumental in creating the mounds. The proponents of this theory may have studied the mound prairies of the North, but surely not those of the warm coastal plains of southern California.

In 1941, soil-scientist C. C. Nikiforoff published a long report on his studies of mounds in the Central Valley of California, principally in Tulare County. The mounds here are so similar in shape, size, and arrangement to those of Puget Sound that certain photographs from the two areas appear to have been taken from the same station. In two respects, however, the regions are different: in Tulare County the mounds are underlain by a stiff clay hardpan and in the rainy season may be surrounded by water a foot or two deep, whereas in Puget Sound the mounds are underlain by coarse gravel and rarely, if ever, stand out as islands. Nikiforoff concluded that the "hog-wallow micro-relief" was perhaps the result of ground-water pressure from the Sierra Nevada pushing up through countless "windows", now represented by mounds, in the hardpan of the valley.

The mounds in the Central Valley are so numerous, or were when the pioneer farmers arrived on the scene, that a special implement, the "Fresno Scraper," has been devised for the purpose of leveling them off and making the ground fit for cultivation. The machine is still widely used.

The foregoing statements high-light the history of research on Mima-type mounds. In 1941, Walter W. Dalquest was engaged in a survey of the mammals of the state of Washington. As he extended his field observations to the prairies near Mima, he was at the same time enrolled in a course in glacial geology at

the University of Washington. Here he learned that the origin of the prairie mounds was a mystery. About then the idea struck him that the mounds are the handiwork of pocket gophers over untold periods of time. When he broached the idea to old-timers born and raised on the prairies, they commonly put tongue in cheek and cautiously remarked, "W-e-e-l, they must have been pretty big gophers." This is a not illogical conclusion in view of the fact that the Mima Mounds are among the most spectacular—if not the largest—structures created by any mammal.

The gopher of the Western states, *Thomomys*, is a ratlike, brownish rodent that burrows in the soil of prairies and mountain meadows and along stream channels in the desert. It seldom ventures aboveground (as does the ground squirrel) and never enters the shade of the forest (as does the mole). It feeds on fleshy roots and often pulls an entire plant, root-first, into its subterranean chamber. The "pocket" part of the gopher's name refers to a deep, fur-lined pouch in each cheek. The pouch is about the size of an ordinary thimble and is used for carrying food, nesting material, and dirt. With this pouch to serve as a hod, with a pair of powerful forepaws for digging, and with the ability to run backward as well as forward in its burrow, the gopher is well equipped to excavate its labyrinthine tunnels.

Our theory of the origin of the Mima Mounds by gopher activity may be summed up as follows: A few tens of thousands of years ago, the Puget Sound prairie was laid down by rivers draining from the Vashon Ice Sheet. At first, the rivers were powerful and were able to carry the large boulders now found in the substratum of the prairie. Later, the rivers were quieter and were able to carry only the fine silt that, richened and darkened by the addition of grass-root humus, now composes the topsoil.

As soon as vegetation captured the raw new soil, we suppose that pocket gophers came in from the unglaciated country to the southward, advancing perhaps a few hundred feet in a gopher generation. By the time they reached the southern end of Puget Sound they encountered a barrier, the evergreen forest that had been racing against them to occupy the new land. There they were stopped, and, to the present day, no gophers are found on the lowlands of the Pacific coast north of southern Puget Sound. To be specific, the northern limit of the gopher range is Point Defiance Park, in Tacoma.

We can picture then, thousands of years ago, gophers rooting through the thin silt of the Puget Sound outwash in search of plant roots. At certain places they dug deeply into the gravelly subsoil in order to make nest chambers well protected from prowling bear, wolf, or wildcat. Areal spacing of the nest chambers corresponded to the size of the "territory" of each animal. The center of an old territory now marks, we believe, the center of a modern mound.

In excavating for its nest chamber, the gopher was instinctively led to dig deep into the bedded gravel, regardless of the effort involved. When the animal ran into a large boulder it undermined the obstruction and allowed it to settle. Thus, we now find, at the base of most mounds, a concentration of coarser materials. On the other hand, in foraging daily for food over its home range, the gopher was driven by less powerful instincts. When it encountered a bothersome rock in its path, it simply passed around it, shoving dirt along as it went. Thus, we find plainly exposed in the intermound hollows large boulders that were doubtless at one time buried in the topsoil.

Where the mound and its bed are in contact, there are found "mound roots," long a puzzle to geologists, which are simply abandoned gopher tunnels now filled with black silt contrasting in color with the yellow gravel around it. (They call to mind the peculiar devil's corkscrews, or *Daemonelices*, of the Nebraska sediments. Once described as fossil plants or animals, the corkscrews are now generally believed to be the casts of burrows of extinct rodents.) We can

imagine that, in cases where a gopher mound was abandoned by its owner for some reason or other, the nesting chamber collapsed and caused a depression at the crest of the mound, a characteristic feature of many of the mounds on Mima Prairie.

In fancy, it is easy to picture the start of a Mima Mound. It is less easy to account for its growth. For reasons that may never be known, the gophers carried more dirt toward the nest than away from it. Perhaps some biologist will suggest an experiment whereby the growth of a Mima-type mound can be studied from start to finish. At present, we do not know whether the mounds on the Puget Sound and other prairies are still growing, whether they are in equilibrium with the forces tending to reduce them, or whether they are shrinking.

In reviewing our evidence in support of the gopher-origin theory, we realize that most of it is indirect. We cannot say that we have seen a gopher, or a family of gophers, build a giant mound. Yet, as each new fact with regard to the mounds is uncovered, it seems to strengthen the gopher theory. And, what is perhaps more important, no counter-theory based on the action of nonliving forces (such as wind and water) approaches a satisfactory explanation of the peculiar structure and arrangement of the mounds. The following facts have led us to our conclusions:

1. Mima-type mounds are distributed along the Pacific Coast exclusively in the range of the pocket gopher. On the north, both the mounds and the gophers terminate abruptly in the vicinity of Puget Sound.
2. Burrowing animals with habits similar to those of the gopher, namely, the ground squirrel (*Citellus*) and the mole (*Scapanus*), are known to occur on many of the mound prairies. We may deduce, however, that these animals are not pertinent to the formation of mounds since there are no ground squirrels in western Washington and no moles on most of the mound prairies of California.
3. Mima-type mounds are found only where there is a thin layer of workable soil on top of a dense substratum. It is significant that the substratum is of no particular geological formation. Thus near San Diego and Fresno, the substratum is a hardpan of cemented soil; a few miles southeast of Mount Hood, in Oregon, the substratum is basaltic rock; and in Puget Sound it is bedded gravel.
4. Where gophers are working in deep sandy soil unlimited by a basement they never form Mima-type mounds. In other words, their up-and-down movements are not restricted or localized. In deep soil near Olympia, Wash., only fifteen miles from the mound display at Mima, gophers have been working for untold years, and the surface of the ground is still so level that it is used as an airfield.
5. The usual agent in the formation of hillocks and mounds is geological deposition of one kind or another. This agent can hardly be responsible for mounds of the Mima type. Deposition, whether by ice, wind, or water, depends on a moving vehicle, and movement always results in a deposit which is aligned in one general direction. Mima-type mounds, as may be seen from aerial photographs, are unoriented. Also, deposition does not produce round mounds on a sloping terrain, as are occasionally seen on the gopher prairies.
6. For similar reasons, the agency of erosion may be dismissed. Erosion is generally the result of a moving vehicle. We may point out, further, that on the Puget Sound prairies, the mounds are draped the year around with a mossy turf that protects them from wind and rain-water erosion. And, in countless cases, the hollows between the mounds are completely closed depressions from which there is no rapid outflow of water—simply drainage through the porous gravel bed.
7. Only by a liberal use of the imagination can we conceive of a set of

geological forces capable of producing the elaborate structure of the mounds, namely: the fluffy, unstratified soil of the mound adjoining a distinctly bedded substratum; the presence of "gopher-size" rocks in the mound as compared with the heavy cobbles beneath and beside the mound; the curious dip in the substrate beneath the mound; the mound roots; and the sunken depression usually found on the summit.

The reader may be disturbed to learn that there are no gophers on Mima Prairie, where climax examples of the mounds appear. This fact is of little importance, however, since there is clear evidence that gophers once lived there. Through some unknown agency—fire, flood, or pestilence—they were wiped out. Once gone from the prairie, they would not return, for the prairie is now isolated from surrounding gopher range by a river and a forest. Since the Mima Prairie Mounds are identical in structure with others only a mile away where gophers are found at the present time, we feel confident in stating that both series of mounds are of common origin. And, as we have pointed out, Mima Prairie is only one among scores of plains along the coast where Mima-type mounds occur.

Finally, we should like to pose three questions, the answers to which some enterprising naturalist may be led to seek:

First, what are the dynamics of mound formation? Were the present mounds built in a matter of years? Centuries? Do conditions of the environment favor their growth at the present time?

Second, does ground water at certain times of the year and in certain localities act in the same way that a soil hardpan does, to force the gophers into mound-building activity?

Third, how widespread in North America are gopher mounds of the Mima type? Shortly before his death in 1942, government naturalist Vernon Bailey told us that he had puzzled over Mima Prairie for years and wondered whether some giant gopher might have lived there long ago. He also said that in his extensive travels he had seen similar formations in southwestern South Dakota, southwestern Louisiana, eastern Texas, and many other parts of the West. Only in California, Oregon, and Washington have we had an opportunity to study them.

ETM-003 THE HILLOCKS OR MOUND-FORMATIONS OF SAN DIEGO, CALIFORNIA

Barnes, G. W.; American Naturalist, 13:565-571, 1879.

Possibly the more famous Mima Mounds are related to those around San Diego.

The surface geology of many sections of the Pacific slope is characterized by innumerable hillocks or small mound-like formations, either sparsely distributed or occupying quite densely areas of considerable extent. These formations, variable in size and structure in accordance with local conditions concerned in their production, exist in many parts of California and on the coast north of it, and are especially abundant and well defined in Southern California.

The following conclusions are based upon observations of them chiefly in the vicinity of San Diego:

In their most common type the mounds may be described as rounded eminences, or knolls, rising from one to four feet above the surrounding surface or the depressions between them, and ranging from ten to fifty feet in diameter. They are generally nearly circular and distinct, but are, in some instances,

ETM-003 MOUNDS AND PIMPLED PLAINS

confluent or elongated. They are separated by wide and irregular areas or by narrow intervening depressions, the latter containing, in stony places, accumulations of cobblestones. They are confined to no geological structure or quality of soil, and are found on sloping lands, on the higher mesas and lower levels.

Any attempt at an explanation of their origin and the mode of their formation must be based upon the assumption that they are modern modifications of the earth's surface and are due to natural agencies; and evidences abound on every hand that the causes concerned in their production are still active in the formation of new and in the maintenance of the old ones; and hence in this vicinity they may be seen in all the stages of their growth, from small rudimentary cones to the fully developed knolls.

Several agencies acting successively or simultaneously have been concerned in these formations. Each mound marks a spot where formerly grew a shrub or cluster of shrubbery, which served to fix its location and which exercised an important influence in the successive stages of its development. The shrubs which seem to have been chiefly instrumental in these results are the Rhus laurina, the Simmondsia californica and the Isomeris arborea; the former undoubtedly having been principally instrumental in the creation of the more recent as well, perhaps, as the most ancient ones in this vicinity. These plants are fitted for the office they perform by the nature of their growth, which is in compact groups or clusters, with many stems starting from the earth near together, the branches and foliage forming a dense mass resting closely upon the ground, and with beds of massive roots; while the distribution of the groups is strikingly similar to that of the mounds in their typical form and arrangement.

Dust set in motion and borne along by the winds is arrested by the shrub and, together with its fallen leaves, accumulate within and around it, and, as is seen in thousands of instances in this vicinity, an elevation of many inches is produced in this manner alone, in many cases covering the lower branches, and in case of the Simmondsia especially, nearly enveloping the whole plant. The



gopher, subsisting upon roots and preferring for its operations the loose soil about them, is, in exceptional cases, an adjunct of the wind in heaping up material about the plant. Of the thousands of these clusters of shrubbery which have come under my observation, a very large proportion show unquestionable evidences of these agencies in elevations more or less marked about them, the surface portions of them at least being generally composed of a light loam of dust and decaying leaves. While the loose earth of which the deposit is composed is protected by the branches and foliage of the plant, the more solid earth beneath is also protected from the wash of rain by its massive roots, while all around erosion goes slowly on, facilitated by the peculiar susceptibility of the soil to wash, a quality familiar to the casual observer.

Instances doubtless exist in which the mounds have been more or less fully developed without the aid of those forces which elevate the earth above its original level, but the shrub and the rain wash have been constant factors.

In the course of time the plant dies—is smothered by the drift which nearly covers it, or is destroyed by the fires which annually sweep over extensive tracts of country. Thus deprived of its protection, the winds in turn, and the rains which fall upon it wear down the top of the loose deposit, and to some extent widen its base. While this is going on the surrounding earth, or interspaces, are being continually lowered by the action of water. The wash always being greater at the base than at its summit, its tendency is to perpetually maintain or increase the prominences.

The presence of beds of roots, well preserved as well as in the different stages of decay, within many of the more modern fully formed structures, upon the surfaces of which it is known from observation that no vegetation has grown for many years, is strongly suggestive of a relation between them of cause and effect. In the oldest ones all traces of the original roots have long since disappeared.

A well known effect of timber and shrubbery everywhere is to impede the drainage of water which falls among it, and so these groups of plants serve to diffuse the currents—which would otherwise be concentrated into gulleys—whose meanderings may be traced in all directions among the mounds, thus conducing to the symmetry of their form and arrangement.

The influence of wash in these results is the most marked on moderate slopes, though sometimes seen on quite steep ones and on comparatively level places, but if upon levels, the latter are so situated as to receive the gathered waters from neighboring slopes. In a situation of this character near at hand the water, after traversing a surface of considerable extent among fully developed mounds, converges into a gully and a surplus flows off to the sea.

Evidences of the potent agency of the winds in results of greater magnitude than these need not be adduced. We need only refer to the sand dunes of Scotland and the shores of the American lakes. It is a matter of common observation here that during the prevalence of one of the "sand storms" of a few hours duration, which visits us once or twice annually, several inches of dust is deposited in places suited for its lodgment, yet the work here ascribed to the wind is mainly carried on by prevailing breezes from the ocean. In situations exposed to concentrated wind currents or their sweep over loose earth or traveled roads, the cones are the most sharply defined, showing that in such circumstances the work goes more rapidly on.

As a minor and exceptional agency I may mention that in the later stages of the formations large excavations are sometimes made by the burrowing of animals, which are afterwards filled with debris, while the matter thus brought to the surface remains to augment the elevation. Hills formed in open spaces by animals do not constitute nuclei for mound-formation; composed as they are of a substratum in which no grass or other vegetable takes root and protects them from

dissolution, they crumble away leaving but a bare and level spot.

To recapitulate; in the incipency of the formation the elevation is composed entirely of a deposit heaped often abruptly about the plant, but pretty soon the influence of erosion is manifest in the subsidence of the base.

Next the plant perishes, and, deprived of its protection, the summit is reduced and the base widened as it is lowered till finally a remnant of the deposit has become so assimilated and compact as to constitute a more permanent summit or it has totally disappeared, leaving the summit at or below its original base.

Reasons for the appearance of these phenomena so exclusively on the Pacific slope and the arid plains of the West, are that the combination of causes resulting in their production there are seldom found elsewhere, to wit; the growth of shrubbery in compact clusters suitably distributed, with low and dense foliage, the presence of burrowing animals, the great susceptibility of the soil to wash and, I may add, the steady prevalence of winds from a single quarter, and the absence of forests which would otherwise influence winds and surface drainage.

Note.—Since the foregoing was written it has been suggested to me by a gentleman whose opinions have much weight, that the wind exercises an influence in excavating the earth around and between the shrubs of which the mounds are a sequence. While there is no evidence of such action in this vicinity, the explanation doubtless holds good in sections of the country in which a loose or sandy soil prevails. The mounds of this vicinity are found almost exclusively on the upland which, when dry, is quite firm and is not perceptibly acted on by the wind, yet sweeping over a considerable surface it gathers enough of soil, in time, to make large deposits about the shrubbery. Sandy soil is exceptional, and is found usually only in the valleys which are comparatively small in extent. In such situations the suitable vegetation does not so commonly exist, there is more protection from the winds, and the rains, generally light, are so readily absorbed that no surface-wash takes place.

It has also been suggested that pebbles and rocks form nuclei around which accumulations of soil remain and conduce to the production of the hillocks. It must be conceded that this is possible, and in certain qualities of soil and with certain kinds of rock quite probable. In this vicinity, however, in no stage of the process are the stones imbedded in the mounds found to be bare, or protruding, or to hinder in any manner the action of water on the soil; on the contrary, in a soil so easily disintegrated by water, the stones hold their positions by an uncertain tenure, and are so readily rolled from their cavities, as the earth is washed away from them, as to rather facilitate than retard the process of erosion.

ETM-004 THE SAND MOUNDS OF LOUISIANA AND TEXAS

Koons, Frederick C. ; Scientific Monthly, 66:297-300, April 1948.

The small mounds that dot portions of the coastal plains of Louisiana and Texas, aptly called "the pimpled plains," have aroused speculation on their origin. Most of the observations so far reported have been superficial, and much of the evidence is merely theoretical or hearsay. When I first saw the mounds on a trip to Texas in 1903, I was told that they were caused by gas blowouts. Later my prolonged residence in Texas afforded opportunity for careful and lengthy study. It is my purpose to review briefly the literature on the subject, to state the results of my investigations on the composition of the mounds and their relation to the underlying strata, and to present my conclusions based on observations covering fifteen years.

The mounds under discussion extend from southwestern Louisiana along the coastal plain southward and westward toward Mexico. I have not observed them south of the latitude of Port Lavaca, Texas. The width of the belt of their occurrence is less than 100 miles and was about 60 miles wide where I made my study. They occur invariably on level plains having a surface soil of clay more or less mixed with sand, little or no drainage, and in regions of abundant periodical rainfall.

The surface soil of the type plain where my studies were made is about 18 inches in depth, underlaid in places by lenses of quicksand from 1 inch to 4 inches in thickness. Then comes 15 feet of clay so impervious to water that after a prolonged wet season of as much as three months' duration the clay at a depth of 3 or 4 feet will be apparently dry and present the same appearance to eye and touch that it does after an extended dry season lasting for months. This clay bed is underlaid by a sand stratum of 12 feet and that by another clay stratum of 4 feet. Under the latter is a stratum of water-bearing gravel and sand. The sand between the clay strata is dry at all times, regardless of the surface conditions. Moreover, the amount of water in the water-bearing stratum is in no way affected or controlled by local conditions of precipitation. There is no connection between the underground water and the surface.

The mounds themselves are circular, and their height varies as their diameters, but their relief is not over 24 inches. In composition they are identical with the adjacent soil, which is a clay loam with a varying percentage of sand; but often the percentage of sand is slightly greater than that of the outside area. There is no rock of any kind in the soil nor in the underlying strata until the bottom of the second clay stratum is reached. However, where there is an underlying sand lens there may be found at the bottom of the sand a few pebbles of water-worn gravel, and in some localities there is a small percentage of ironstone nodules, or "buckshot."

Generally, for each mound there is a corresponding depression on one side, and sometimes, but not often, on two sides. These depressions are oriented in no particular way, are oblong, and their width and length vary as the diameter of the mound.

Some of the mounds are pitted at or near the center, usually by one, and rarely by as many as three, small pits.

The mounds show no regularity of distribution and exhibit no trend. There is no evidence of stratification of any sort. In diameter they range from 4 to about 30 feet, but a few are larger.

[At this point Mr. Koons discussed and rejected eight hypotheses that were suggested in previous literature to account for the origin of the mounds. They were: (1) Differential settling of sediments, (2) segregation of mineral matter, or concretion on a large scale, (3) vertical seepage of water under hydrostatic pressure, (4) gas blowouts, (5) wind drifts, (6) anthills, (7) uprooted trees, (8) manmade. We are omitting his arguments on these hypotheses and other references that he made to the literature because we are primarily Interested in his own observations and conclusions.—Ed.]

As a result of my own observations and investigations on the mounds I offer the following solution to the problem of their origin: The mounds were made by the pocket gopher, Geomys bursarius, to enable the builder to keep out of the water. Where there is surface or underdrainage the mounds are not made because they are not needed.

Since the pocket gopher is found on the Great Plains from the south side of the Saskatchewan to the Gulf of Mexico, it may be objected that the gopher does not build mounds on other areas that are sometimes flooded. That is true; but it is also true that both surface and underdrainage are vastly superior to that of the pimpled plains. The surface gradient of the latter is from 3 to 6 feet

per mile, which to the eye is a flat surface. The soil, as before mentioned, is thin. The mean annual rainfall at Houston, Texas, is about 50 inches, about twice that of the Great Plains, and is not evenly distributed throughout the year. When the weather is wet it is apt to be very wet for a long period, and of course the dry periods may also be quite long. The underlying clay subsoil being impervious to water, as before explained, the thin stratum of topsoil soon becomes saturated and then flooded. So there is a considerable difference in this respect between the Great Plains east of the Rocky Mountains and the pimpled plains. One familiar with the Gulf coastal plain may urge the objection that not all of it, even in the pimpled plains area of Texas, is of the character described. While that is a fact, it is also true that unless it is of the type character there will be no pimples. For example, there are localities where the type soil borders on an area of heavy, "Black waxy" land, Beaumont clay, which is from 6 to 10 feet or more in depth. The line between the two is often rather sharply defined. There will be mounds on the one and none on the other. Why? The deep soil has a certain amount of underdrainage and, being deeper, much more water is required to saturate and flood it. Furthermore, few gophers will be found there. The gopher's favorite food does not grow very well on black land. Being like putty when wet and very hard when dry, it is difficult to work.

I had in mind, in mentioning the foregoing type locality bordering on black land, the southern part of Colorado County, Texas, southwest of the village of Garwood. Going west from Garwood, we traverse about a mile of black land, very sticky and very deep. It is moundless. After crossing the Mustang Creek we are suddenly out of the black land and on the pimpled plain, which is more or less sprinkled with the typical mounds. A journey of about 14 miles southwest brings us to Sandy Creek, which flows through a timber belt about 2 miles wide at that point. We are still in the type locality as to soil, except that in places the creek has built up levees. Gophers are abundant on these higher lands as well as on the plain, but there are no mounds.

The manner of constructing a mound is this: the gopher opens his burrow to the surface and piles up a mound of loose earth 2 to 3 feet in diameter and often as much as 18 inches high. He does not use this mound as a residence unless the water forces him to do so. As the plains are usually pastures and there are many cattle on them, the cattle paw and horn down the newly made mounds and scatter the fresh earth. The gophers rebuild it as occasion demands, and it is as often torn down. If the cattle do not demolish it, the weather eventually will; but I have never known the cattle to fail. Before the advent of the cattle there were buffalo, which served equally well.

The material that was piled up was not taken from immediately under the mound, but was carried from a distance through a runway excavated to one side. Usually but one runway was made in the early history of the mound. This was extended, and the excavated material pushed up into place on the dump until the carry became too long; then a branch was made from the first run and earth carried from that until the distance again became too great, whereupon another branch was started; and so on. In that way the depression, which was caused by the eventual settling of the excavated area, came to be on one side of the mound and not all around it. It was simply a borrow pit from which material was taken for the fill: i. e., the mound. In that way the mound came to be made round and the depression oblong. The gopher in his tunneling sometimes went well down to the clay stratum, and if there happened to be a sand lens there he used it, for it was easy digging. In that way it came about that he sometimes put a trifle more sand in his structure than one finds in the surrounding soil. Often he made his mound near some small, shallow lagoon or natural depression. The bulbs of certain lilies were to be had there, and they

were harvested when the water evaporated, as it was sure to do in summer. Around such places also grow sedges, Cyperus esculentus, which furnish desirable tubers, if we may judge by the amount harvested and stored.

I have now accounted for the mounds and the depressions, but what about the small pit or pits often found near the center? They are secondary, and the gopher had nothing to do with them. We must remember that the gopher uses the mound as an island of refuge and does not generally live there. He prefers to locate his living quarters and storehouse elsewhere, ordinarily. After he has first built up his small mound, and each time thereafter when he works on it, he plugs the opening to the surface when work stops. And he plugs it so skillfully that three minutes after he has finished one may cut a section through it with a spade and find it very hard to determine which part had been hole and which undisturbed soil. But he has neighbors, and when after some years of labor a fair-sized mound has been built up, it often happens that some skunk, civet cat, or mink decides that the mound is a nice, high site for a residence and makes a burrow. The newcomer may, and often does, strike a gopher's tunnel, which is enlarged to meet the needs of the invader. But the new burrow, unlike the gopher's is kept open, since the occupant goes out and in nightly. It is this opening, enlarged by dogs or other animals digging at the entrance or by cattle stepping on the earth just over it and caving it in, that causes the small pits.

To prove the gopher hypothesis, I noted the initiation of mounds and made observations on their progress for some years. Two were noted about three miles apart on trails that I frequently traveled, and their locations marked for identification. They were observed shortly after the initial mounds were thrown up and were kept under observation some years. After five years both had attained fair size and would readily have been classed by the casual observer as "sand mounds." One of them was abandoned when it was included in a rice field and partly plowed down and later flooded by irrigation. I have never observed a new mound in an old rice field, no matter how long it may have been abandoned for rice culture, provided the check levees had not been plowed down. The gophers appropriated the levees and, not needing mounds, did not build any.

If this solution of the origin of the mounds in question be the true one, then a geological problem has been solved only to raise a biological one. Dare we charge an animal with such a radical change of life habits to meet special environmental needs? Does that noted hydraulic engineer, the beaver, neglect to build a dam where there is plenty of water? How did he become a dam builder in the first place? May not another rodent become an engineer?

I have been over a good deal of the Great Plains region from the Dakotas to the Gulf; the pocket gopher is found more or less in the entire territory, but nowhere except on the pimpled plains have I noted any such work as I have herein attributed to it.

In well-drained regions where gophers are present, they are evidenced by many small earth heaps, which are waste dumps for material excavated in making runways, but these are not enlarged and are merely by-products in the construction of tunnels; whereas on the pimpled plains it would seem that the mound is more than that and that tunneling is sometimes carried on for the purpose of borrowing material from one place for use in another.

Obviously, we must call in expert evidence in the case and, since we have chased our geological constructor into a biological hole, we must consult the biologist.

The biologist says yes in answer to the foregoing questions and presents some evidence in support. The ground squirrel of the Columbia plateau occupies a region of abundant food, but water fails in midsummer. So he simply

digs deep, shuts himself up, and goes to sleep until the following spring, according to Shaw. This habit is a local one. Allee, of the University of Chicago, cites the case of the blue heron, which in the forest regions of the East nests in tall trees, but in the treeless wastes of the Great Basin builds on the ground a structure of reeds and mud 4 or 5 feet high in order to place the nest above the water—an entire change of habit. Osgood, of the Field Museum [now the Chicago Natural History Museum], answered the questions in the affirmative and cited the case of the fire ant. On the flood plain of the Amazon thousands of these ants assemble into a compact ball that floats until the flood subsides. The outer individuals drown, but the queen in the center and the inner ones survive. Thus many animals adapt themselves to unusual environments.

ETM-005 "MUD LUMPS" AND MOUNDS NEAR NEW ORLEANS

Simons, M. H. ; American Naturalist, 16:418-420, 1882.

While attached to a Coast Survey party working on the Mississippi river, I was informed that there were three "Indian mounds" back in the edge of the swamp; on examination they proved to be "mud lumps," but of a shape and material different from those at the mouth of the river. I have looked over various works on geology, but can find no notice of any of these elevations so far above the river mouth, and no very satisfactory explanation of the manner in which they are formed or of the forces forming them. The mounds above spoken of are on the left bank of the river, on the place of Mr. Louis Le Bourgeois, fifty-five miles above New Orleans, they are about one and a half miles back from the river and just in the edge of the swamp. The largest one is 40 feet in height and 144 feet in diameter, conical in shape with no signs of a crater. 300 yards N. x E. from it is a smaller one, 15 feet in height and 80 feet in diameter. 250 yards E. N. E. is another, not more than 5 feet in height and 20 feet in diameter. Formerly the large mound was entirely surrounded by a circle of these small elevations, but they have been leveled during the process of cultivation. The surface soil around the mounds is the usual black alluvium of the valley.

Mr. Ogden, U. S. Navy, and myself cut into the large mound from the top to a depth of 18.5 feet, and found as follows: There were less than two inches of vegetable mold, and the remainder of the excavation was cut through a hard orange sand; it was so hard that the pick had to be used continuously; single valves of shells, apparently *Corbula*, were abundant as far down as we went; to a depth of ten feet the shells were mostly soft and calcareous, below that they were all silicified; limestone concretions were very abundant, though generally small; six feet below the surface there was a layer or bed of these shells, with the valves separate; this bed was three feet wide and long, and about three inches thick, and immediately underneath it the sand was black, in some case rough concretions were attached to the shells. There were numerous black spots about the size of buck-shot thickly scattered throughout the whole extent of the excavation; under the microscope these black spots proved to be aggregations of sand; we considered them probably the result of the destruction of minute shells. Eight feet below the surface there was a handful of blue clay and sand mixed, and a little below that a handful of fine gray sand. Half way down the side of the mound I found the same material and appearances, and at the beginning of the slope, the orange sand lay thirty inches from the surface; thirteen feet out from

the bottom of the mound, it was necessary to cut through forty-seven inches of alluvium to reach the orange sand, and nineteen feet out it could not be found at all. *

About 100 yards from the mound there was a deep ditch, in the bottom of which there was indication, in one place, of the orange sand, eight feet below the surface, but I think that it had been brought from a greater depth by crayfish. The large mound is thickly covered with a growth of magnolia, ironwood, cane and a species of wild climbing vine. During the summer season, as we were informed, flowers peculiar to the mound are found. From the regular shape of the large mound, broken only by holes dug by treasure-hunting negroes, it seems probable that the mound-builders may have shaped it to suit their ideas of symmetry. On the right bank of the river, some three miles back, and in the swamp, I was told by the negroes there were two other large mounds similar in appearance to the one described above. I did not have time to see and examine them. Below New Orleans I noticed two small irregular lumps, bearing evidence of a crater on one side, in one, and in the center in the other.

At Southwest Pass there is a mound, or elevated area, called a "salt mound," from the well of salt water in the center. The pilots told me that when these lumps, or areas, are thrown up, there are, at first, salt wells on them; the wells are very deep and boil up, apparently from escaping gas; ultimately the wells fill up and disappear. There are frequent vibrations, and horizontal and vertical movements of the land in the passes. On one of the lumps in Southwest Pass there is a well discharging on inflammable gas.

Professor Thomassy examined the Le Bourgeois mound and pronounced it the result of the damming of a subterranean stream. Professor Lyell thinks that they may be caused either by the binding of the stratum of earth deposited in the bottom of the river by its own weight and motion, down the grade of the stream, or by the vertical pressure of accumulations of gas, or by both.

In one or two works on the antiquities of the mound-builders, there are notices of numerous anomalous mounds, generally of small size, scattered throughout the Mississippi valley. These may be mud lumps similar to the small ones surrounding the Le Bourgeois mound.

ETM-006 SUBMARINE PINGOS IN THE BEAUFORT SEA

Shearer, J. M., et al; Science, 174-.816-818, November 19, 1971. (Copyright 1971 by the American Association for the Advancement of Science)

An abrupt shoaling of the ocean floor in the Beaufort Sea was first noticed in 1969 by hydrographers aboard the C.C.G. S. John A. MacDonald, a Canadian icebreaker escorting the tanker S.S. Manhattan through the Canadian Arctic to Prudhoe Bay, Alaska. The shoal manifested itself as a rapid rise of the sea bottom from 49 to 23 m below sea level, over a horizontal distance of 200 m. This rapid rise was followed immediately by an equally rapid drop to 49 m. On the return voyage from Prudhoe Bay both ships skirted the shoal by passing to the north of its position, and no attempt was made to relocate the feature. For local reference the shoal was christened the "Admiral's Finger."

In response to a lack of detailed bathymetric information on the western Arctic, as typified by this incident, the Canadian Hydrographic Service in 1970 embarked on an extensive mapping program in the Beaufort Sea and adjacent regions. Coincident with this program a major research project was undertaken by the Department of Energy, Mines and Resources, designed to investigate the nature and distribution of marine sediments along the southeastern margin of the Beaufort Sea. During the course of these two projects, bathymetric, gravimetric, and magnetic data, complemented by seismic reflection data, side-looking sonar records, and numerous grab and core samples were mapped on a reconnaissance basis over the whole of the southeastern continental shelf, and in greater detail over selected areas of interest.

One of these areas was chosen with a view to carrying out a detailed survey of the Admiral's Finger and the surrounding area, in order to learn more about the nature and extent of the apparent topographic anomaly. The site of this survey, which was carried out by the C. S. S. Baffin, covered 500 km² at a point located near the edge of the continental shelf, about 120 km northwest of Atkinson Point, Northwest Territories (Fig. 1, inset map). Sounding data were obtained over 9000 km of parallel tracks at an average separation of 0.5 km, and gravity and magnetic data were obtained over 4000 km at an average separation of 1 km.

Unexpectedly, this detailed survey revealed a large number of underwater mounds interrupting an otherwise smooth sea floor (Fig. 1). Each mound bore, in size and shape, a superficial resemblance to the Admiral's Finger. As far as could be inferred from detailed topographic examinations by means of launches, the mounds were generally irregular and asymmetric in form, with one side steeper than the other. The diameters of the bases averaged 400 m, and the elevations, from base to peak, 30 m. In most cases, a shallow (0 to 10 m) moat or depression surrounded the base of the feature.

A total of 78 mounds was located in the survey area, with minimum depths above their summits ranging from 15.4 m to more than 45 m. Their distribution appeared to be random. Several were grouped in clusters, others were paired, and the remainder were scattered singly within the 70-m isobath.

During the same period, similar features were discovered outside the survey area by investigators aboard the C. S. S. Hudson and C. S. S. Parizeau, who were engaged in hydrographic and scientific activities. Seven were identified on the east side of Mackenzie Canyon (at 69°55'N, 137°10'W) by means of side-scan sonar. A seismic reflection profile was obtained over another feature located at 70°51'N, 131°72'W, just to the east of the survey area described above. These observations indicate that more shoals may exist on the unmapped portions of the continental shelf of the Beaufort Sea, particularly since the seven mounds located by means of side-scan sonar were not detected by the ship's echo-sounder. The implications with respect to deep-draft shipping in the western Arctic are serious, since the features represent a hazard to navigation in ice-infested waters.

No detectable correlations were apparent between these small-scale topographic features and the geophysical observations. The magnetic field, measured to a precision of 1 gamma, displayed no evidence of shallow sub-bottom structure. As expected, the gravity field was dominated by the shelf-edge anomaly, and the shipboard system, measuring to a precision of 1 mgal, gave no indication of perturbations associated with the sea-floor mounds. Sub-bottom reflectors, as viewed in the seismic reflection trace, show little deviation from the horizontal, which rules out a diapiric or intrusive origin, as earlier suggested.

The similarity in the morphology of these submarine features with pingos (hills that have a central core of ice) on the Tuktoyaktuk Peninsula, 120 km to the south, suggests a similar mode of formation. Two modes of origin will be

discussed: terrestrial and submarine.

In the first case these offshore features are presumed to represent the submerged portion of a group of pingos all formed originally above sea level. During the last glacial maximum the worldwide sea level is thought to have been some 100 to 125 m below its present level. On emerged areas of the Beaufort Sea outside the ice margin, permafrost probably existed in response to mean annual air temperatures that were below 0°C. A landscape similar to that now present above sea level may have existed, and scattered lakes, in which winter ice did not freeze to the bottom, would have been present with the associated depression of the permafrost layer beneath these insulated areas. Shoaling of these lakes either by infilling or draining (the latter commonly by shoreline retreat) would have caused freezing to the bottom during the winter with the subsequent formation of pingos in a manner similar to that suggested by Mac Kay (discussed more fully below). However, examination of the effect of even moderate wave action at the present shoreline, where leveling is fairly complete and rapid, raises doubts with respect to the possibility that these proposed pingos could have survived the postglacial transgression.

In the second case, these offshore features are presumed to be pingos in the genetic sense, which have formed subsequent to oceanic transgression and in the submarine environment. If the shoaling of the lakes described above did not occur prior to the incursion of the sea, the unfrozen pore water in the interstices of the sediments occupying the permafrost depressions could have remained unaffected by the transgression. Synchronous with this transgression of the sea was the exchange and mixing of the fresh lake water with the seawater. (The mixing of seawater with freshwater in the pore spaces of the sediments underlying the original lake basis is believed to be very slow or nonexistent because of the sealing effect of the fine lacustrine sediments and the progressively increasing thicknesses of marine clay.) The thermal regime in the lake bottom was therefore altered from that of an unfrozen freshwater layer to one governed by the temperature of the seawater. In this respect, most temperatures recorded on the sea bottom in the Beaufort Sea in August and September 1970 were below -1°C, many being the lowest temperature possible without freezing (-1.8°C) for the given salinity. If we assume that conditions similar to those of the present existed at the time of transgression, the displacement of fresh water by the colder salt water would have been accompanied by a migration of the 0°C isotherm downward into the sediments beneath the lake basin. Freezing of the interstitial water and the associated upheaval of the overlying material would have resulted, in a manner similar to that occurring on dry land.

With the thermal regime established, it is pertinent to mention briefly the pressure relations involved in the formation of a pingo. The two major mechanisms (not mutually exclusive) described in the recent literature are (i) upheaval due to the hydrostatic pressure of expelled pore water and (ii) uplift due to the frost-heave process. Given the temperature conditions discussed above, the first water to freeze is the pore water just beneath the impermeable lake bottom sediments. As the frost line advances, excess pore water is expelled into the unfrozen material. This surplus water, combined with the sealing effect of the frozen lake bottom, causes a buildup of hydrostatic pressure which is sufficient to lift the overlying layer to the heights observed. In a fine-grained soil, this migration and accumulation of pore water may be followed by the formation of ice lenses and by volume expansion (frost heave), which will produce uplift over and above that already caused by hydrostatic pressure. A load of 40 m of water, or any other load influencing equally the overburden and pore-water pressures, will not affect the frost-heave phenomenon which develops in the soil upon freezing. Uplift due to hydrostatic pressure will occur when the pressure exceeds the binding strength of the impermeable frozen layer plus the pressure

ETM-007 MOUNDS AND PIMPLED PLAINS

of the 40-m water load, which is very small (about 4 atm) as compared with the total pressures involved.

The minimum age of a mature pingo can be estimated by determining the time required for the freezing of the permafrost depression beneath the original lake bed. The size of this depression must first be calculated by assuming that the ice core of the pingo has the shape of a cone with a radius of 200 m and a height of 20 m. If this core is pure or almost pure ice, then the volume of sediment from which the ice was derived will be equal to the volume of the cone divided by the product of the sediment porosity (30 percent) and the ratio of the volume expansion of ice to the total volume of ice (as 0.1). If the depression is approximated by a cylinder with a radius of 400 m (the size of the original lake basin), its depth is calculated to be about 60 m. The time needed for the 0°C isotherm to reach this level depends mainly upon the thermal conductivity of the sediment, the surface temperature, and the geothermal heat flow. If we assume reasonable values for these parameters, it would take about 5000 years for the frost line to reach this depth.

In the case of submarine pingos, this reasoning implies that marine transgression must have occurred prior to 5000 years B. P. This date is supported by worldwide curves of postglacial sea level submergence, which indicate transgression at these depths (30 to 70 m) taking place well before 5000 years B. P.

Note added in proof: Additional pingos have been discovered on the floor of the Beaufort Sea near the site of the survey area of 1970.

ETM-007 PECULIAR EARTH-HEAPS IN MISSOURI

Blankinship, J. W. ; American Antiquarian, 11:117, 1889.

While traveling in southern Missouri, my attention was attracted to a remarkable series of mounds along all water courses. I afterwards observed them as extending over nearly all the southwestern portion of the state, very abundant in many localities. They are in the alluvial soil, and are always near a water course or spring—barely more than a hundred yards distance. In Howell County, Mo., and Fulton County, Ark., they are more plentiful. They are often four feet high and thirty to forty feet in diameter—usually arranged in rows parallel to the stream and at a distance from fifteen to forty yards apart. They may be found around ponds which have no outlet and whose waters vary but little during the year. Much of the land is covered with heavy timber, which grows indiscriminately upon the mounds. I have examined several, but have found no evidences of human remains. They have been attributed by the inhabitants to beaver, prairie dogs, gophers, and Indians, both modern and ancient. It is possible they are the remains of houses built of sun-dried bricks.

The submarine canyons incised in continental shelves around the world in relatively recent geological times may indicate that sealevel was then thousands of feet lower than it is now. On the other hand, these colossal gorges may have been cut by some force we do not yet recognize.

ETS-001 THE UNDERLYING CAUSES OF SUBMARINE CANYONS

Shepard, Francis P.; Science, 83:484, May 22, 1936.

Here is a concise statement of the enigma of the submarine canyons by a noted oceanographer.

Investigations of submarine canyons carried on for a number of years with the cooperation of the Coast and Geodetic Survey, the Geological Society of America, Scripps Institution and other organizations have revealed that these sea-floor canyons have all the characteristics of river canyons and are distinctly different from fault valleys. Also tests of the idea that the submarine canyons might be the product of currents have produced negative results so that they have evidently been cut by rivers. The significance of this sub-aerial erosion on the present sea floor is particularly disturbing, since the submarine canyons extend out to depths of from 2,000 to as much as 10,000 feet and are found off practically every coast of the world. Also all available evidence favors a Pleistocene age for the canyons. Accordingly, there is the implication that the coasts of the world were greatly elevated above their present positions during the glacial period. That all the continental margins both off stable and unstable coasts could have been subjected to such movements in comparatively recent times is scarcely credible. The alternative that there have been sea-level changes connected with the cause seems much more reasonable. Such changes are indicated not only by the submarine canyons but also by many of the phenomena of coral reefs and by oceanographic data from various parts of the world. The only cause of sea-level change which does not meet with almost insurmountable objections is that of glacial control. It seems quite possible that the continental glaciers during some of the earlier glacial epochs may have been sufficiently thick and sufficiently extended to have allowed a lowering of 3,000 feet or more. While such a lowering was probably insufficient to account for the deeper canyons it is felt that it would have resulted in the development of a universal canyon system which, connecting with much older sunken canyons in some places and modified by subsequent sinking elsewhere, would account for the present situation.

ETS-002 OUR SHRINKING GLOBE

Landes, Kenneth K.; Geological Society of America, Bulletin, 63:225-240, 1952. Discussion; 63:1069-1074, 1952.

In this address to the AAAS in 1951, Landes nicely summarizes some data which tend to support the past existence of much lower sea levels. If sea levels were truly many thousands of feet lower in the recent past, where did the present oceans come from? Was catastrophism involved? What of man during this period? The enigmatic submarine canyons underscore this mystery.

ETS-002 SUBMARINE CANYONS

Submarine Canyons and Allied Features

Factual Data. It was dissatisfaction with all current explanations for submarine canyons that started me on this study. The many theories advanced to explain these features are described and discussed by Shepard.

So much has been written about submarine canyons in recent years that it will not be necessary to describe them in detail. A most comprehensive account of their distribution is given by Shepard. They cut the submerged continental slopes and shelves of all continents and of many islands including the Bahamas. Most of the larger canyons connect with rivers, and as a general rule with the larger rivers. Smaller canyons notch the continental slope but do not penetrate far into the continental shelf. Most of the canyons that do approach the present shore line have been diminished and even obliterated through infilling brought about by shoreline processes.

Many canyons have cut through the mantle into underlying bedrock. The bedrock encountered ranges in vulnerability to erosion from shale to granite. Studies made of the canyons off the California coast have shown the presence along the canyon walls of limestone, well cemented sandstone, conglomerate, basalt, and granite as well as soft Tertiary material. The maximum depth reached by the canyon floors is certainly greater than 12,000 feet and may even be greater than 15,000. This is the stumbling block that prevents widespread acceptance of canyon cutting by subaerial erosion.

The authorities are in rather general agreement that the canyon cutting took place during the Pleistocene. The bedrock incised is as young as late Tertiary. Veatch and Smith state that the greatest erosion along the Atlantic-facing continental slope was during the first and last glacial stages. Shepard and others have pointed out that some of the canyons in higher latitudes were modified by glacial excavation. These canyons not only have the characteristic cross section of glaciated valleys, but some contain moraines.

Another submerged feature suggestive of erosion is the terrace. According to Tolstoy "the continental slopes are now known to show in many cases a step-like succession of horizontal or imperceptibly sloping shelves or terraces". The same author notes evidence of terracing on the flanks of the flat-topped submerged mountains (seamounts or guyots) rising above the ocean floor south-east of Cape Cod. The mid-Atlantic Ridge between depths of 10,000 and 15,000 feet contains "a succession of flats which for the lack of any better term have been called terraces". Emery describes "deep terrace-like structures on the flanks of Eniwetok Atoll at a depth of about 4500 feet. This compares closely with the depth of the flat top of the seamount tied to the northwest side of Bikini Atoll by a narrow neck. Bikini itself has a terrace at a depth of 13,000 feet.

At least 35 mountains rise to heights of 3,500 to 12,400 feet above the floor of the Gulf of Alaska. Some of these have the symmetry, the slope, and the alignment of volcanoes. Most of the shallower mountains have flat tops at a depth of 2400 to 3000 feet. Some of the flat tops are as much as 8 and 9 miles in diameter. Similar seamounts have been found elsewhere, especially in the western and central Pacific. These truncated cones rise 9000 to 12,000 feet above the ocean floor, and the flat summit levels range as a general rule from 3000 to 6000 feet below sea level. The flat top is in many instances bordered by a gently sloping shelf which extends outward 1-2 miles. The summit levels of adjacent peaks may differ by as much as 1000 feet. Many seamounts have been used as foundations for atoll construction.

There is fairly general agreement that seamounts are volcanic cones that have been truncated by wave erosion. The flat submerged banks may have similar origin.

Ripple marks have been photographed on the sea floor at depths as great as 4500 feet. Shallow water faunas, in addition to the reef-building types previous-

ly mentioned, have been found at even greater depths. Examples range from Foraminifera to larger mollusks. Sand, gravel, and even cobbles have been dredged from the floors of submarine canyons far from shore and to depths of 12,000 feet or more. Recent coring in the Atlantic, along the eastern continental slope of North America, has shown the presence of beds of sand interbedded between layers of clay referred to as abyssal in type. However, I am skeptical in regard to the precise dating given these ocean-bottom deposits, based on Foraminifera. If I read Phleger correctly all the Pleistocene species of Foraminifera are still living. There are cold-and-warm-water types, and as the ice sheets advanced these types shifted south, later to return with the retreat of the ice. Therefore a "normal post-Wisconsin assemblage of Foraminifera known to be living in the region at the present time, could equally well be assigned to one of the pre-Wisconsin interglacial stages, or perhaps even to an interstage of the Wisconsin itself.

Subaerial Erosion Hypothesis. The subaerial hypothesis as an explanation for the submarine canyons is as old as the discovery of the canyons themselves. It is based on the striking parallelism between canyons cut by rivers running off the land and the canyons cut into the submerged continental slopes and shelves. Shepard has summarized the evidence favoring subaerial erosion of the submarine canyons. These valleys resemble land canyons in every possible respect with one exception, which is discussed later. The submarine canyons have steep walls with V-shaped cross sections. They follow a winding course and have accordant tributaries. The dimensions are comparable to those of larger land canyons. Some have wide flat floors toward the outer end, and others terminate in deltas. Natural levees have been observed. Hess noted that some of the submerged river valleys of the Bahamas even show a trellis pattern, presumably due to the structural situation.

An undaunted few have tried to explain the extreme sea-level fluctuation necessary to permit canyon cutting by subaerial processes. Shepard and du Toit have invoked warping of the continental borders. Hess and MacClintock convinced that no answer other than subaerial erosion can be the right one, suggest as a possible solution a change in the ellipticity of the sea surface perhaps due to sudden decrease in rate of earth rotation. Von Engeln postulates interior earth conditions which would produce a temporary increase in density. This would cause the ocean bottoms to sink to greater depths, and sea level would "decline in a significant degree".

My explanation is that during one of the Pleistocene glacial epochs the ocean basins subsided to such an extent that sea level was lowered the 15,000 feet or whatever is needed to account for subaerial canyon cutting. I have calculated that if all the sea floor now lying at depths below 13,300 feet (4000 meters) were to subside 20,000 feet, all the ocean floor above 13,300 feet of water depth would be emergent. This would expose all our submarine canyons except, perhaps, the mouths of the deepest ones. I cite this figure merely to show that unheard-of subsidences are not necessary to expose the canyon-cut continental slopes. Furthermore, this extreme subsidence only had to happen once. To obtain the other glacial epochs, a sealevel lowering of 3000 feet probably would have been sufficient. The deep-sea floor (below 4000 meters) would have to subside a little over 5000 feet to produce this emergence.

I do not know which of the four Pleistocene glacial epochs was the one of maximum withdrawal, but I suspect that it was one of the later ones, for there is some evidence of higher-level deltas through which the present canyons have cut. Each sea-level lowering would cause resumption of excavation and headward erosion in those parts of the valleys lying above that particular ocean-water level. Each resubmergence stopped the canyon cutting, but by the end of the Wisconsin epoch a few canyons had eroded headward across the entire width of the shelf.

The upper ends of many of these submerged valleys were subsequently filled by shoreline processes of erosion and deposition.

Although a few others have been willing to consider a sea-level lowering of several thousands of feet, owing to ocean-floor subsidence, they have not been able to swallow a return of sea level to within a few hundreds of feet of its former position, and have therefore dropped the idea with considerable dispatch. According my concept of the mechanics of contraction, it would be even stranger if the sea level did not return to the same approximate level as before! When the ocean basins subsided, owing to a contracting interior, a condition of isostatic disequilibrium was established. Very shortly, in terms of geologic time, the continents also subsided and came to rest at the level of isostatic equilibrium.

At least two other arguments have been raised opposed to subaerial erosion of the under-water canyons. The one exception to the complete parallelism between submerged canyons and those on the continents is the long profile. In the case of the mature land streams this profile is concave. It is not concave in the Monterey sea valley and in other submarine canyons with the possible exception of the Congo. However, I do not believe that one should expect a young consequent stream running down the continental slope to show a normal profile. It was busily engaged in converting its initial slope to a normal profile when submergence interrupted the job. The mighty Congo came closer to finishing this conversion than most other streams. Another argument is the cutting of canyons in partially enclosed seas such as the Mediterranean and the Sea of Japan to depths far below the level of the sill separating the sea from the open ocean. The best explanation that comes to mind is that graben faulting within the enclosed sea has dropped the canyon area below its original level.

I concur with Hess and others in believing that the flat-topped seamounts or guyots are volcanoes truncated by wave erosion. The lowering of present sea level from 3000 to 6000 feet would be adequate. The discordance in summit elevations can be explained in two ways: (1) the higher volcanoes (in terms of depth to the flat top) were not even in existence when the lower ones were truncated by wave action, or (2) erratic grabening of the fragmented Pacific Ocean floor has dropped the seamounts varying distances.

Other Suggested Explanations. Opposed to the concept of subaerial erosion are some of the most highly respected and revered heroes of modern geology. Most of the substitute ideas produced by this galaxy of mental stars although ingenious are none the less unpalatable. The leading alternate explanation is the turbidity-current hypothesis. Sired by Daly and nurtured by Kuenen, and by Ewing and associates, the turbidity-current hypothesis reached maturity with the publication of a symposium in 1951.

Briefly, turbidity currents are silty underflows that have been observed in Lake Mead and several other artificial lakes in the United States as well as Lakes Geneva and Constance in Europe. They have also been produced synthetically in a tank, and there is no doubt that under proper conditions silty water slides down the sloping floor of reservoir, lake, or tank much like water flows under air.

Proponents of turbidity currents credit them with depositing the deep offshore graded sand deposits (coarser elastics such as the cobbles are supposed to ride down on submarine landslides) and with carrying shallow-water formaminifera out to depths far beyond their normal habitat, as well as cutting canyons into the continental slope and shelf.

Turbidity currents have not been found in the ocean in spite of the fact that some mighty rivers carry sediment to the heads of submarine canyons having gradients far steeper than those found on the floor of Lake Mead. It is perhaps more than a coincidence that none of the witnessed examples of turbidity currents have been where silt-laden masses of fresh water entered larger masses

of salt water. Where rivers, such as the Congo, enter the sea, the fresh water rides out over the salt water, carrying its sediment with it until the checking of velocity causes the sediment to sink into and through the underlying quiet salt water.

I claim that the finding of graded elastics and misplaced (shallow-water) faunas deep beneath the sea is not prima facie evidence that they were carried there by turbidity currents; that the finding of cobbles does not prove that they were transported by submarine landslides; and that photographs of ripple marks lying at a depth of 4500 feet do not necessarily mean that they resulted from current action operating at that depth. In any other environment, sand, gravel, and cobbles are recognized as stream deposits, especially where they occur on canyon floors, and in the fans and deltas at the mouths of canyons. Misplaced faunas are found at great depths in rigid reefs, and their position there is generally recognized as due to subsidence, but we are told that loose, misplaced forams must have been carried in! I likewise believe that deep sea-floor current ripples, like the truncated seamounts, are relics of shallower water.

What manner of logic allows us to accept evidence, such as marine strata, of a sea-level far above present datum of 25,000 feet, but causes us to run from evidence of a sea-level depression of 25,000 feet? By what reasoning do we assume that current sea level is also (within 200 or 300 feet) minimum sea level? Would it not be just as logical to assume that the present sea level (when the continents and the ocean basins are in isostatic adjustment) is closer to median sea level? And when we do lower sea level a couple of hundred feet why do we limit that lowering to the amount of water that could have been removed to make ice caps and mountain glaciers? We raise sea level thousands of feet by diatrophism. Is this a one-way process? Why can't we lower sea level the same way? What is so sacrosanct about current sea level? (PP- 231-235)

ETS-003 WHEN THE MEDITERRANEAN DRIED UP

Hsu, Kenneth J. ; Scientific American, 227:26-36, December 1972.

After describing the discovery of salt plugs and evaporites beneath the Mediterranean (both suggesting this Sea had dried up at one time), Hsu goes on to relate the discovery of submarine canyons around the edge of the Mediterranean. These deeply cut gorges are taken as evidence of a much lower water level in the past. Could the very similar submarine canyons on oceanic shores indicate that the oceans were also thousands of feet lower at one time in geological history?

Soon after we returned to port Ryan received a letter from a Russian geologist, I. S. Chumakov, who had learned of our findings through an article in The New York Times. Chumakov was one of the specialists sent by the U. S. S. R. to Aswan in Egypt to help build the famous high dam. In an effort to find hard rock for the dam's foundation 15 boreholes were drilled. To the Russians' amazement they discovered a narrow, deep gorge under the Nile valley, cut 700 feet below the sea level into hard granite. The valley was drowned some 5.5 million years ago and filled with Pliocene marine muds, which are covered

ETS-004 SUBMARINE CANYONS

by the Nile alluvium. Aswan is 750 miles upstream from the Mediterranean coast. In the Nile delta boreholes more than 1,000 feet deep were not able to reach the bottom of the old Nile canyon. Chumakov estimated that the depth of the incision there might reach 5,000 feet, and he visualized a buried Grand Canyon under the sands and silts of the Nile delta.

Chumakov was not the only one who had been puzzled. Oil geologists exploring in Libya had also had their share of surprises. First, their seismograms would register anomalies; there were linear features underground transmitting seismic waves at abnormally high velocities. Drilling into the anomalies revealed that they are buried channels incised 1,300 feet below sea level. The geologic record tells the same story: vigorous downcutting by streams and sudden flooding by marine waters at the beginning of the Pliocene. Frank T. Barr and his co-workers of the Oasis Oil Company, based at Tripoli in Libya, concluded in a report that the Mediterranean must have been thousands of feet below its present level when the channels were cut. They could not get their manuscript published in a scientific journal, since no one would accept such an outrageous interpretation, (p. 35)

ETS 004 [EFFECTS OF ALABAMA CLOUDBURSTS]

Anonymous; Nature, 52:552, October 3, 1895.

In a report on the Coosa coal-field, published by the Geological Survey of Alabama, Mr. A. M. Gibson describes some remarkable effects of the great "cloud-bursts" which devastated that region in 1872, and are still conspicuous after a lapse of over twenty years. Clean-cut channels, in one case sixty feet wide and three or four feet deep, are described as extending down the mountain sides. They were formed by the direct force of the downpour of water, and along them were carried great masses of rock—one weighing a hundred tons—earth, trees, &c., which formed moraine-like masses at the base or were scattered far over the lower ground.

This entry demonstrates the tremendous cutting power of catastrophic flood waters. Could the submarine canyons have been created thus?

SUBJECT INDEX

Proper names are so profuse in the quoted sources that a thorough index of them would overwhelm the book: therefore, only the most important proper names, such as Meteor Crater, are indexed here. Authors and sources are indexed separately. Because place names are highly variable, they are categorized first by continent/ocean and then by country or some other reasonable subdivision. An Arizona entry, for example, will be found under North America/1*. S. AZ.

- Africa, lack of Deluge traditions. ELD-002
 - Afghanistan, ERS-003
 - Egypt, ETS-003
 - lack of Deluge traditions. ELD-001, ELD-002
 - Ghana, ETC-001, ETC-005
 - Ivory Coast, ERM-003, ERM-005
 - Libya, ERB-003, ERM-003, ESP-001
 - Sahara region, ERS-003
 - South Africa, EBS-002, ESP-001
- Animals in rocks, all EBR
- Antarctica, EBS-002, ESP-001
- Araguainha Dome. ETC-006
- Arctic muck (see Muck, Arctic)
- Arctic Ocean, EBM-010, EBM-011. EBS-001, EBS-002. ETB-002. ETM-006
- Ark. ELD-001, ELD-002
- Asia. Deluge traditions, ELD-001
- Asia. China, Deluge traditions, ELD-002
 - ERR-004, ERS-005
- India, ETC-001
 - Deluge traditions, ELD-002
- Indochina, ERM-003
- Indonesia, ERM-003
- New Siberian Islands. EBM-009.
 - EBM-010
- Philippines, ERM-003
- Siberia, all EBM. ELC-001, EBS-001, ESD-002, ESP-001. ETB-002, ETC-001. ETC-002. ETC-003
- Thailand. ERM-004
- Asia Minor. Arabia, ERB-004, ERB-005. ERS-001. ERS-003, ERS-004, ETC-001
- Dead Sea. ELD-001
- Persia. ETC-001
- Syria, ELD-001
- Astroblemes, all ETC
- Atlantic Ocean, ETE-00:i. ELG-001
 - Bahamas, ETS-002
- Atlantis, ELG-001. ERM-000
- Aurichalchon, ELG-001
- Auriferous gravels, ESD-004
- Australia, EBM-004, EBS-002. ERM-003. ERM-004. ERM-005. ESP-001, ETC-001
 - Deluge traditions, ELD-002
- Australites, (see ERM)
- Avalon, ELG-001
- Babylonian Deluge traditions. ELD-002
- Barking sands (see Sands, musical)
- Barringer Crater (see Meteor Crater)
- Bediasites. all ERM
- Black Death, ELC-001
- Boneyards (see Muck, Arctic)
- Bosumtwi Crater. ERM-003. ETC-001. ETC-005
- Boulder fields, all ERR and ESP. ERB-006
- Boulder trains. ESD-002. ESD-005. all ESP
- Boulders, fitting, ERB-006
- Boulder., percussion figures. ERG-002
- Brazil, legendary island. ELG-001
- Brendan, ELD-001
- Brent Crater, ESD-002, ETC-004
- Bushveldt Complex, ETC-006
- Cambrian extinction, EBE-004
- Campo del Cielo Craters. ETC-001

SUBJECT INDEX

- Canyon Diablo Meteorites (see Meteor C rater)
- Carolina Bays. ESD-006, ETB-001, ETB-002
- Cataclysms (see Catastrophism)
- Catastrophism. EBM-001, EBM-002, EBM-004, EBM-00B, EBM-007, EBM-010, EBM-011, EMR-005, ERM-002, ERM-003, FRM-004, ESC-001, ESC-002. ESD-001, ESD-004, ETS-004 and the demise of Atlantis. ELG-001 due to polar flipping. EOA-003 initiated by supernovae and solar outbursts. EBE-002 and mass extinction. EBE-001 Sodom. ELD-001
- Caves, bone. EBM-001. EBM-004
- Central America. Deluge traditions, ELD-001. ELD-002
- Chaldean Deluge tradition. ELD-002
- Chimera, the. ELD-001
- Clearwater Lake Crater. ERM-003
- Climate changes, all ELC in Arctic. EBM-010. EBM-011 astronomical causes. EOA-001. EOA-002 correlated with magnetic reversals. EMR-004 due to supernovae and solar outbursts. EBE-002
- Coal, with fossilized trees embedded, ESC-002 unsolved origin, ESC-001
- Coal money. ERB-009
- Comet impact, all ETC, ESD-001
- Concretions. ERB-009
- Coon Butte (see Meteor Crater)
- Continental drift. EMA-001, EMR-001, EOA-003
- Continental submergence, all ETE
- Craters, all ETC
- Cretaceous extinctions. EBE-002. EBE-004
- Deluge, all ELD. EBM-001, EBM-004 accompanied by earthquakes. ELD-001 accompanied by luminous phenomena, ELD-001, ELD-002 due to waters from within earth, ELD-001. ELD-002 and legend of Atlantis, ELG-001 traditions as indicators of cultural diffusion, ELD-002
- Deucalion Deluge tradition, ELD-001
- Diffusion of culture, after Atlantis. ELG-001
- in Deluge tradition, ELD-002
- Dinosaurs, extinction, EBE-003
- Dinosaur leather. ERG-002
- Drayson Theory, EOA-001, EOA-002
- Drift, all ESD, EBM-006, EBS-004
- Druid Deluge traditions, ELD-002
- Earthquakes, and the Deluge, ELD-001
- Elysian Fields, ELG-001
- Emergence of land, all EBS, all ETE, ELC-001, ESD-004
- Equinoxes, precession, EOA-001, EOA-002
- Eskimos, ELC-001
- Ether-drift experiments, EOA-002
- Europe, Deluge traditions, ELD-001, ELD-002
- Alps, ESD-002, ESI-001
- Czechoslovakia, ERM-003
- Denmark, ERS-003
- Estonia, ETC-001
- France, ERG-002
- Germany, ERM-003, ERS-001, ERS-003
- Great Britain, EBR-003, ELC-001, ERB-002, ERR-003, ERS-001, ERS-002, ERS-003, ESD-002, ESI-003, ETC-001, ETE-001
- Greece, ELD-001
- Greenland, ELC-001, ESP-001
- Iceland, ELC-001, ESP-001
- Ireland, ELG-001, ERG-002
- Norway. ELC-001
- Poland. ESP-001
- Scandinavia, EBS-001, ELC-001, ESP-001
- Sweden, EBS-003
- Evolution, ESD-004, ESI-001
- Extinctions, all EBE, all EBM correlated with magnetic reversals and vulcanism, EMR-005 and supernovae, EBE-002, EBE-004
- Fairy crosses, ERB-001
- Felsenmeer (see Boulder fields)
- Fish, mass fossilization, EBE-001
- Floods, all ELD, ESP-003, ETE-002 (see Deluge)
- Fossilization, lack of today, EBE-001
- Fortunate Isles, ELG-001
- Frog, mummified, EBR-002
- Fulgerites, ETC-001, ETC-007
- Geomagnetic reversals, all EMR, ERM-004
- Gilgamesh Epic, ELD-001
- Glacial deposits, all ESD
- Glacial period (see Ice Ages)
- Glaciation, lack of in Siberia, EBM-006

SUBJECT INDEX

- Glass deposits, ERB-003, ETC-001
(See also Vitrified areas)
- Gopher theory of mound formation, ETM-002, ETM-004
- Guyots, ETE-006, ETS-002
- Gurlt's cube, ERB-002
- Harras, ERB-005
- Hebrew Deluge tradition, ELD-001, ELD-002
- Henbury Crater, ERB-003, ETC-001
- Hillock formation, all ETM
- Hog wallows, all ETM
- Hole, anomalous, ETC-001, ETC-007
- Holleford Crater, ESD-002, ETC-004
- Hy Brasil, ELG-001
- Ice Ages, all ESD, ESP-003, ETE-001
- Isle of the Seven Cities, ELG-001
- Ivory Coast tektites, all ERM
- Ivory islands, EBM-004, EBM-008, EBM-009
- Jebel Nakous, ERS-001, ERS-003, ERS-004
- Kilmichael Structure, ERM-003
- Kimeridge coal money, ERB-009
- Koran, ELD-001
- Lakes, oriented, all ETB
- Lakes, rectangular, ETB-002
- Lava flows, ESD-004
- Legends, all EL
- Lot's wife, ELD-001
- Lyonesse, ELG-001
- Magnetic reversals, all EMR
correlated with earth's wobble, extinctions, vulcanism, EMR-005
recent, EMR-003
- Magnetism, asymmetry of earth's field, EMA-001
correlated with climate changes, EMR-004
self reversal, EMR-002
- Mammoths, all EBM
carbon dating, EBM-006
extinction, EBE-004
modes of death, EBM-005, EBM-006, EBM-007, EBM-011
- Manicouagun Crater, ETC-006
- Mastadons, EBM-004
- Mediterranean Sea, ETE-008, ETS-003
- Mercury, advance of perihelion, EOA-002
- Meteor Crater, ESD-002, ETC-001, ETC-006
- Meteorite, Dr. Gurlt's cube, ERB-002
- Meteorite impact effects, all ETC, ETB-001, ETB-002
- Meteorites, all ERM, ERB-005, ERB-008
- Microtektites, ERM-004, ERM-005
- Miller, Dayton, ether drift experiments, EOA-002
- Mima Mounds, ETM-001, ETM-002
- Mirages, sources of legendary islands, ELG-001
- Moldavites, all ERM
- Moon, origin, EMA-001, ERM-002
- Moundbuilders, ETM-005
- Mounds, all ETM
dumrlins, ESD-002
- Mount Ararat, ELD-001
- Muck, Arctic, EBE-004, EBM-002, EBM-003, EBM-006, EBM-007, EBM-008, EBM-009, EBM-010, ETB-002, ETE-002
- Musical sands, (see Sands, musical)
- Mutations, radiation-induced, EBE-004
- Myths, all EL
- Niobe, The, ELD-001
- Noah's Deluge, ELD-001, ELD-002
- North America, ELC-001
Deluge traditions, ELD-001, ELD-002
- North America (except U.S.), Canada, EBM-007, EBS-004, ERM-003, ERX-001, ESD-002, ESP-001, ETC-004, ETC-006, ETE-002
- Mexico, ERB-007
- North America (U.S.), AL, ETS-004; AK, EBM-006, IBM-007, EBM-009, EBM-010, ETB-002; AZ, ERB-008, ERG-001, ETC-001, ETC-006; CA, ESD-004, ETM-002, ETM-003, ETS-002; CT, EBR-001, ERB-009; East Coast, ETB-001; FL, ETB-002; GA, ERM-003, ETB-001; Great Lakes area, ESD-002; LA, ETM-004, ETM-005; ME, ERS-003; MD, ETB-001; MA, ERS-002, ERS-003, ESP-002, ESP-003, ESP-004; MI, ERS-003; MS, ERM-003; Miss. Basin, ESD-005; MO, ETM-007; NV, ERS-003, ERS-006, ERX-003; NH, ERS-003; NJ, ERS-003, ETB-001; NM, ESP-004, NY, ERG-002, ERS-003, ESD-002, ESP-003, ESP-005; NC, ERS-003, ESD-006, ETB-001, ETB-002; OK, ERX-001, ERX-002, ETM-001; PA, EBR-002, ERR-001, ERR-002.

SUBJECT INDEX

- ESP-005: KI. ERS-003: SC. ERS-003, ETB-001. ETB-002: TN, ESD-006: TX, ERM-003. ETC-001, ETC-007, ETM-004: VA, ERB-001, ERS-003, ETB-001; WA. ETM-002: WI. ERS-003. ETC-006: WY. ESI-002
- Odessa Crater. ETC-001
Oriented lakes, all ETB
Overthrusts. all ESI
- Pacific Ocean. ERM-004, ETE-006
 birthplace of moon, EMA-001
 Christmas Island. ESP-001
 Fiji Deluge traditions, ELD-001
 Hawaii, ERS-001, ERS-002, ERS-003, ETE-005
Parallel Roads of Scotland, ETE-001
Patterned ground, all ESP. ESD-006, ETB-002
Periglacial phenomena, all ESP, ERR-001, ESD-006
Percussion figures, ERG-002
Permafrost, all ESP. ETB-002
Permian extinctions, EBE-004
Petrification, EBM-010
Petroglyphs, potentation, ERG-001
Pimpled plains, all ETM
Pingos. ETM-006
Pleistocene, all ESP, EBM-006, EBM-009. ETB-001, ETB-002, ETE-003, ETM-001. ETM-006. ETS-002
 extinctions. EBE-003. EBE-004. EBM-004
Planetoid, destroyer of Atlantis. ELG-001
Polar flipping. EOA-003
Poles, magnetic, asymmetry. EMA-001
Polygonal ground, all ESP
Polygonboden. all ESP, ETM-001
- Quicksand, dry, ERB-004. ERS-006
- Radiation and extinctions, EBE-002, EBE-004
Ries Crater, ERM-003
Ringing rocks, all ERR
 associated with ancient ruins, ERR-002
 biological effects, ERR-002
Rock cities. ESP-005
Rock fields, all ERR, all ESP, ERB-005
Rock glaciers, ESP-003
Rocks, erupting, ERX-001, ERX-002
Rocks, moving, ERX-003, ERX-004, ESP-003
- Rocks, ringing, all ERR
Rocks, spherical, ERB-007, ERB-008
- St. Brendan, ELG-001
Salt pillars, ELD-001
Sand Sea, ERB-003, ERM-003
San Diego hillocks, ETM-002, ETM-003
Sands, musical, all ERS
Sealevel changes, all EBS, all ETE, all ETS, EBM-010, ETM-006
Self-reversal of magnetic fields, EMR-002
Shale balls, ERB-008, ETC-001
Siberian Meteor (*see* Tunguska Event)
Sinbad Legend, ELG-001
Singing sands (*see* Sands, musical)
Solar activity and catastrophism, EBE-002
Sonorous sands, all ERS
South America, Deluge traditions, ELD-001
 Argentina, ETC-001
 Brazil, ETC-006
 Chile, ERM-001, ERS-007
 pampas, EBM-004, EBS-002
Sounding stones, all ERR
Species, creation, EBE-004
Stone circles, all ESP
Stone spheres, ERB-007
Stone stripes, all ESP
Strata, reversed, all ESI
Strew fields, all ERM
Submarine canyons, all ETS
Submergence of land, all EBS, all ETE, all ETS, ESD-004, ESP-004, ETM-006
Superposition, Law, all ESI
Supernovae and extinctions, EBE-002, EBE-003, EBE-004
- Tektites, all ERM
Thrust faults, all ESI
Toads in rocks, EBR-001, EBR-002
Tunguska Event, ERM-004, ETC-001, ETC-002. ETC-003
Turbidity currents and submarine canyons, ETS-002
- Unconformities, EBE-004
Uniformitarianism, EBM-004, EBM-006, ESD-004, EBE-001, EBM-001
- Vitrified areas, ERB-003, ETC-001
Vulcanism, ERB-007, ESD-004, EMR-005
- Wabar Crater, ERB-003, ERB-005, ETC-001

Waterspout and the Deluge, ELD-002
 Whalebones high above sealevel, EBS-001,
 EBS-002, EBS-003, EBS-004
 Whirlwinds and the Deluge, ELD-001

Wobble, earth's, and climate changes.
 EOA-003
 correlated with earthquakes, EMR-005

AUTHOR INDEX

Arnold, A. W. . EBR-001

Barksdale, William L., ETB-002

Barnes, G. W. , ETM-003

Beals, C. S. . ETC-004

Bell, Robert. EBM-011, ETE-002

Berkland, James O. , ESD-006

Black, Robert F. . ETB-002

Blankinship, J. W. . ETM-007

Bolton, H. Carrington, ERS-001. ERS-
 002. ERS-003, ERS-004

Bouldin, Powhatan. ERB-001

Broadhurst. F. M. . ESC-002

Cade, C. M. . ERB-002

Cargill. S. T. . EOA-002

Chamberlain, T. C. . ESD-005

Cohen, Daniel. EBE-003

Conway. Martin. ERX-004

Davis, Chester A. . ESD-003

Donnelly. Ignatius. ESD-001. ESD-002

Eardley. A.J.. ETE-007

Emerson, B. K. . ELD-001

Escher, B. G. . ERG-002

F. . L. . ERM-001

Farrand, William R. . EBM-006

Faul, Henry, ERM-003

Florensky. Kirill P. . ETC-003

Fuller, Curtis. ERX-002. ERX-003. ETC-
 007

Geike, Archibald, ETE-001

Gibbons, John, ERR-001

Glass, Billy P. . ERM-004

Gold, T. . EOA-003

Gray, M. H. , ERS-007

Gregory, J. W. . ESI-003

Heezen, Bruce C.. ERM-004, ETE-004

Hess, H. H.. ETE-006

Hitchcock, Edward, ESP-003

Hopkins, Albert A. . ELG-001

Howe, Oliver H. . ESP-002

Howorth, Henry H., EBM-002, EBM-003,

 EBS-001, EBS-002, ELC-001

Hsu. Kenneth J. . ETS-003

Jones, Harold S. . EOA-002

Julien, A. A.. ERS-002, ERS-003

Kennett, J. P. . EMR-005

King, Clarence, ESD-004

Knechtel, Maxwell M. . ETM-001

Koons. Frederick C. . ETM-004

Landes, Kenneth K. . ETS-002

Lee, Oliver J. . EMA-001

Longfellow. D. W. . EMA-001

McLeod. N. M.. EOA-002

Merrill, George P. . ETC-002

Nelson, Richard J. , ERR-003

Oakley, Kenneth P. . ERB-003

Offord, Joseph, ERS-005

Perry, J. B.. ESP-004

Pierce, William G. . ESI-002

Price. George M.. EBE-001, ESI-001

Prouty. W. F. , ETB-001

Raymond. Loren A. . ESD-006

Restelle, William. ELD-002

Russell, Dale, EBE-002

Sanderson, Ivan T. . EBM-007

SOURCE INDEX

Scheffer, Victor H. . ETM-002
 Schlossman, Steven. ERR-001
 Shearer, J. M.. ETM-00i;
 Shelley, David. ERB-000
 Shepard, Francis P. . ETS-001
 Shufeldt, R. W. . EBR-002
 Simons, M. H. . ETM-005
 Spencer, L.J. . ETC-001
 Stirling, Matthew W. . ERB-007

Taber, Stephen. EBM-009

Talmage, J. E. . ERG-001
 Tingle, Alfred, ERR-004
 Tooker, Charles, ESP-005

Velikovsky, Immanuel, ERB-005. ESC-001

W. . A.S. . EBM-005
 W. . H. B. . ERB-009
 Washburn, A. L. . ESP-001
 Watkins, N. D.. EMR-005
 Wollin, Goesta, EMR-004

SOURCE INDEX

American Antiquarian, 11:117, ETM-007
 American Association for the Advancement
 of Science, Proceedings, 32 251-252
 ERS-002 33:408-413, ERS-003 38:
 137-140, ERS-001

American Association of Petroleum
 Geologists, Bulletin, 41 591-626,
 ESI-002

American Journal of Science, 1:29:353,
 EBR-003 1:49:258-265, ESP-003
 244:772-791, ETE-006 262:858-869,
 ESC-002

American Meteorological Journal. 1 509,
 ERS-006 3:4-5, ERB-004

American Naturalist, 4:565-567, ESP-004
 5:125, EBS-004 11:449-470, ESD-
 004 13:565-571. ETM-003 16:418-
 420, ETM-005

American Scientist. 52:488-497, ETE-007
 Aviation Week, 44, June 17, 1974, ETC-006

Bibliotheca Sacra, 64:148-167, ELD-002

Current Opinion, 61:330, EBM-008

Discovery. 24:36-41, ERB-002

Earth in Upheaval, 96-97, ERB-005 216-
 217, ESC-001

Evolutionary Geology and the New Catastrophism,
 111-112, ESI-001 234-239,
 EBE-001

Fate, 17:10-12, Oct 1964, ETC-007 24:8,
 May 1971, ERX-003 26:22, Nov 1973,
 ERX-002

Geological Society of America, Bulletin,
 9:369-390, EBM-011 54:1433-1548,
 EBM-009 63:167-224, ETB-001 63:
 225-240, ETS-002 63:689-700, ETM-
 001 67 823-866, ESP-001

Journal of Geology, 1:47-60, ESD-005 4:
 653-654, ERG-001 57:105-118, ETB-
 002

Literary Digest, 86:25-26, ETE-005

National Geographic Magazine, 136:293-
 300, ERB-007

Natural History, 79:36-41, Dec 1970, ERR-
 001

Nature, 5:162-163, EBS-001 5:420-422,
 EBS-002 6:24-25, ELC-001 8:46,
 ERR-003 8:301, EOA-001 37:123-
 125, EBM-001 37:200-201, EBM-002
 37:295, EBM-003 38:134, EBS-003
 39:607-608, ERS-004 41:108-109,
 ERM-001 52:552, ETS-004 59:390,
 ERX-004 63:566, ERB-009 68:292-
 298, EBM-005 70:111-115, ETE-001
 73:222-223, ERR-004 77:208, ERB-
 008 77:272-274, ESI-003 81:126-127,
 ERS-007 95:65-66, ERS-005. 105:171,

ERG-002 17(5:447-449, ERB-003 227:
 767-768, ETE-003 227:776, EMR-001
 227:930-934, EMR-005 227:1002,
 EMR-002 227:1377, ERB-006 228:
 199-200, ETE-008 228:1259-1260,
 ERM-005 229:327-329, ETE-004
 229:553-554, EBE-002 232:549-551,
 EMR-004 234:441, EMR-003
 NEARA Newsletter, 6:13, ESP-005
 New York Times, Nov 12, 1948, ERG-003
 New World Antiquity, 19:27-43, ESD-003
 Nineteenth Century, 136:159-165, EOA-
 002 137:237-240, EOA-002

 Pursuit, 2:33-35, EBE-004 2:68-69, EBM-
 010 4:38-41, ERR-002 6:33-35, ERX-
 001
 Ragnarok; The Age of Fire and Gravel, 63-
 64, ESD-001 21-22, ESD-002

 Saturday Evening Post, 239:39, Jan 16,
 1960, EBM-007
 Saturday Review, 65:52-53, EBM-004
 Science, 4:328-344, ELD-001 8:279-280,
 EBR-002 67:489-490, ETC-002 72:
 89, EMA-001 83:484, ETS-001 84:
 394-396, ESP-002 133:729-735, EBM-
 006 152:1341-1345, ERM-003 174:
 816-818, ETM-006 181:651-653, ESD-
 006
 Science Digest, 65:45-52, Mar 1969, EBE-
 003
 Science News Letter, 37:303, ERM-002
 Scientific American, 29:212, EBR-001 79:
 394-395, ERB-001 217:33-38, Jul
 1967, ERM-004 227:26-36, Dec 1972,
 ETS-003
 Scientific American Monthly, 4:362-363,
 ELG-001
 Scientific Monthly, 65:283-294, ETM-002
 66:297-300, ETM-004
 Sky and Telescope, 15:296, ETC-004 17:
 284-286, EOA-003 26:268-269, ETC-
 003 30:15, ETC-005
 Smithsonian Institution Annual Report, 1897,
 359-367, ETE-002 1933 , 307-325,
 ETC-001

